SUBSEA CONTAINMENT

A Contract Report for Dome Petroleum Ltd.

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The Centre for Cold Ocean Resources Engineering (C-CORE) was established at Memorial University of Newfoundland in St. John's in 1975. It's initial funding was provided by the Devonian Group of Charitable Foundations of Calgary. This support is being supplemented by grants from governments and industry.

The Centre's mandate is to undertake research that will assist the safe and orderly development of Canada's resources, in which cold and ice frequented oceans are a problem. C-CORE's main concentration of research is on ice, its properties, detection and behaviour.

EXECUTIVE SUMMARY

The result of a small scale empirical testing program indicates that containment of an underwater blowout might be achieved using simple, *ad hoc* techniques and equipment assemblies. A prior understanding of two phase flow in confined spaces and of the dynamic behaviour of gas lift pumps would be essential to the success of a containment operation based on the techniques identified in this report.

If the findings from this study can be extrapolated linearly to a full scale blowout, it should be possible to capture and handle the product from a 30,000 bbl/day, 30 MCF/day blowout with a simple flexible riser or riser bundle with a diameter no greater than 1 metre. Collector cones and elaborate installation and anchoring devices should not be necessary unless the local ocean conditions are highly energetic.

Futher, applying the principles examined in this study it is entirely conceivable that a blowout could be completely contained and subsequently produced using more or less conventional techniques.

ACKNOWLEDGEMENTS

This study was conducted as a broad ranging investigation of ideas and concepts. Many persons have contributed either directly or indirectly to the findings presented here. Not in the least, recognition should go to those who went before us; inventors and investigators who have probed and proposed a vast range of ideas many of which we used in this study. Particular mention should go to Ian Buist who was an active participant as the Dome Petroleum Ltd. project manager. Several "think tank" sessions were held in St. John's at which contributions were made by Jacques Guigne (NORDCO), Richard Niefer (MUN Engineering), and John Jones, Bill Winsor, Gordon Swaters, Gerald Goobie, Tom Laidley and Deborah Diemand (all of C-CORE). The success of our investigations must to a large extent be attributed to Deborah Diemand who translated concepts into hardware and tested them.

E.M. Reimer
Leader, Hydrocarbon Group
C-CORE

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1. INTRODUCTION

The concept of subsea containment of an offshore well blowout has been proposed and investigated several times over the past decade. Particular interest has recently been expressed by operators such as DOME who face seasonal ice problems which would preclude conventional relief operations during a significant part of the year.

AMOP sponsored a subsea containment study in 1978 (Chen) and more recently Norwegian interests have sponsored a number of conceptual and engineering studies of the problem including a recent and very thorough study on blowout control (Mundheim et al 1981).

In this context a joint industry-government workshop was held in Toronto during February 1981 (Meikle, 1981) to review the necessity for action and the technical feasibility of subsea containment. Several generic containment concepts were reviewed. Questions as to the behaviour and effectiveness of all of these devices remained unanswered. A general system design was developed based on a "Sombrero" type cone collector plus a modified tanker. The cost of this system was estimated between 35 and 50 million dollars.

We (DOME/C-CORE) were not convinced that further systems design studies should be undertaken without a general reexamination of collector and riser concepts. All of the concepts discussed were large or complex enough that they would have to be pre-built and stored in case of need. We were interested in examining concepts which would be either simple

enough to be fabricated after the fact or inexpensive enough that storage or wellhead installation would not constitute an inordinate economic burden.

The ensuing study was aimed at the empirical testing of a wide range of concepts some of which originated in house and many of which have been proposed by designers and inventors considering this particular problem. The study was executed as a six week tank testing program preceeded by a number of local "think tank" sessions. We did not consider scaling factors or attempt anything beyond a rudimentary quantification of the results. The single selection criteria was apparent feasibility.

2. TEST FACILITY

All tests were carried out in the deep tank at the Fluids Laboratory of the Memorial University Faculty of Engineering and Applied Science. The tank with dimensions approximately 3 m x 3m x 4 m deep is fitted with side windows and hoist. In order to facilitate video recording of results the tank was specially fitted with 2500 watts of quartz-halogen top lighting and a water filtration system. Data was recorded on 3/4" video cassette.

A fluid discharge system (see Fig. 1) was constructed and ballasted in such a way that it could be easily placed on the bottom of the tank and removed for modification, attachment of containment devices, etc., (Fig. 2). The gas and water delivery system was controlled from a panel at a side window for convenience in testing. The system allowed the metered discharge of 0-50 l/sec (0-100 cfm) air (STP) and 0-2.5 l/sec (0-35 gpm) water from the discharge pipe at the bottom of the tank.

3. RESULTS

3.1 Free Plume

Initial observations were made to assure that the fluid exit characteristics at the discharge pipe were more or less "normal". The behaviour of the air discharge at 17 l/sec conformed with the characteristics observed by Topham (personal communication) and with the recorded behaviour at the DOME McKinley Bay experimental blowout (Dikins & Buist 1981). The gas emerged as a succession of large bubbles approximately three times the diameter of the discharge pipe. This initial bubble would be almost completely detached from the succeeding bubble (VIDEO). The bubbles dissipated as froth within two bubble diameters of the discharge orifice.

In general,the plume would surge and wander at the tank surface over a radius of about 1 metre (maximum). Although a strong vertical circulation cell was expected in the confines of the tank, this was not in evidence. Froth and small bubbles were carried down about 2 metres below the surface. Currents below this depth were moderate, insufficient to move or pick up light debris at the bottom.

The characteristics of the gas discharge were substantially altered when water was injected concurrently with the gas. The bubble forming at the discharge orifice was reduced in size and increased in frequency with increasing water injection rates. At 2 l/sec water and 17 l/sec gas the discharge became a more or less continuous stream no greater than the discharge orifice diameter. The entire plume flow was much smoother; turbulence of

the gas boil on the tank surface was perceptibly reduced.

The plume characteristics over a depth of 4 metres were apparently quite sensitive to the characteristics of the discharged fluid. During a subsequent test of a gas/liquid separation device the fluids exited in a turbulent, finely mixed froth flow condition. The plume behaviour was very smooth and streamlined under these circumstances.

3.2 Flexible Risers

Norwegian testing of a flexible riser system (reported by K. Sojen and P. Teijen at the Toronto workshop) indicated severe problems with flutter which resulted in material failure after a few hours of testing. Stabilization was apparently not attempted.

Because of the low cost of fabric risers and the potential ease in handling, it was felt that a reassesment with a view to flutter abatement would be worthwhile. Tests were carried out with impermeable nylon riser under a wide range of conditions.

3.2.1 Flutter

The previously observed flutter was in evidence with the 50 cm nylon riser fitted directly over the discharge pipe (Fig. 4). The riser flattened immediately as internal fluid was expelled at the top. The injected fluids rose through the tube in a series of separate peristaltic waves (Fig. 3). Evidently the "flutter" in this case was essentially a wave phenomenon generated at the interface between moving fluids of differing densities. With smaller diameter risers the fluid velocities appeared to be higher and the flutter characteristics were

altered (e.g. peak to peak distances were larger).

In all cases the injected fluids generated a lift which entrained excess liquid at the bottom of the riser. The top discharge rate was always such that the riser was in a collapsed fluttering condition. It was suggested that an increase in fluid intake might serve to stabilize the riser behaviour. To this end a short section of 50 cm pipe was used to terminate the riser suspended some distance above the discharge system (Fig. 4c). In this configuration the riser entrained larger quantities of water, its fluttering was somewhat softened or attenuated but was still judged to be intolerable for an operational system.

Two further possibilities were considered for flutter attenuation; choking and stiffening. The former will be discussed here and the latter under the category of reinforced and rigid risers.

By limiting the rate at which fluid products were vented from the top of the riser it was possible to inflate the entire riser and completely eliminate flutter in the process (Fig. 5). The 50 cm riser developed a substantial buoyancy in the process. With the entire riser inflated the bulk density of the internal fluid was about 0.6 gm/cc (estimating from buoyancy). Since gas only was being vented at the top we assumed that a gas/liquid interface had developed at some level in the riser. Necessarily, liquids injected at the bottom were also escaping at the bottom of the riser as was evidenced from the ejection of fine bubbles. The efficiency of the system in capturing gas was essentially 100%, however the large volume of the 50 cm riser seemed to

mitigate against liquid collection (because of the gas/liquid separation).

A second riser with a diameter of 15 cm was constructed using transparent plastic so that the internal fluid behaviour could be observed. With this riser throttled at the top, the internal fluid flow was a mixed froth/bubble flow with significant liquid slip near the walls. The product issuing from the top included both gas and water indicating that liquids could be captured using the smaller diameter choked riser.

The evident physical constraint on the construction of a choked flexible riser would be the cumulative top-to-bottom pressure differential. In order to inflate the riser to a given depth the minimum necessary back pressure must be equal to the external hydrostatic head. In the worst case situation, with the internal fluid density essentially that of gas, the pressure at the top of the riser could be substantial in the case of a deep installation. Large diameter risers of conventional fabrics might not have an adequate pressure rating. Once again steel reinforced, semi-rigid risers seem to be indicated.

3.3 Gas-Liquid Separation

One of the initial concepts in setting up this study was the idea of separating gases and liquids at the seafloor to reduce the problems apparent in handling large volumes of gas, oil and water in a marine riser. Since gas by itself does not pose much of an environmental threat it could be vented at the seafloor. Handling of the remaining liquids would be greatly simplified.

Gas/liquid separation in the petroleum and chemical

processing industry is a longstanding art. A literature search turned up an overwhelming number of references from which a few representative samples were chosen (see Appendix B). There was no clear indication of a particular design which would be suitable for the case at hand. Two concepts were tested:

1) filtration separation using a gas-permeable riser
2) centrifugal separation

3.3.1 Permeable Risers

A gas permeable 7.5 cm riser was fabricated from cotton and installed on the discharge system using a tight coupling. At low gasflow rates (< 2 l/sec) the tube would vent most of the gas at the water surface, however, as flow rates progressively increased gas was extruded from the walls of the tube (progressing from top to bottom). Water injected along with the gas did not reach the surface when gas flow rates were high enough to force gas through the walls of the tube. Evidently liquids were being forced through the tube before the gas. (Since the water injection was annular this may not represent a universal behaviour.)

Separation of gases and liquids using this type of pressure filtration is evidently possible, although difficulties would be encountered with plugging due to high viscosity, debris and sediment in the well product. Control would probably be very difficult to achieve. A double walled system with an impermeable riser external to the permeable system was tested: results were inconclusive; flutter was violent.

3.3.2 Centrifugal Separator

The concept of a gas-liquid separation system integral to a

BOP stack had been suggested at the time of the Toronto workshop. This type of device would have to be designed to permit the passage of a drill string during normal drilling operations.

An annular (coreless) centrifugal separator was constructed and tested on the discharge system. The functional performance was very poor. For such a device to be useful it would have to perform a relatively complete gas-liquid separation. The required performance figure could probably not be achieved without prior knowledge of the fluid characteristics and flow rates. The range of fluid density, gas to oil ratio (GOR), water content, frothing, etc. which can be tolerated by a fixed design is a function of fluid residence time, (i.e. the volume of the device). A pre-installed wellhead device would necessarily be small and would be limited in its fluid handling capabilities; it is not likely that a universal device could be designed.

3.4 Centering forces

Some of the devices tested by Sjoen and Teigen relied on natural centering forces created by the plume. They found that these were relatively weak forces. In addition to an assessment of centering forces acting on specific containment devices we devised a number of experiments to assess the relative effects of fluid momentum and buoyancy.

A spar buoy constructed from a .01 m x 3 m ABS pipe(4"x 10') was sealed and ballasted to float vertically about 2/3 submerged. Its behaviour in the presence of a bubble plume was observed.

Radial surface currents held the spar away from the plume when free floating. If the spar was physically inserted at the

centre of the plume it would list to about 30° with the bottom end held more or less at the (wandering) plume centre and the top end being swept radially. Loss of buoyancy was negligible. The spar was held in this situation by the plume for anywhere from seconds to minutes until the combined instability of the plume and spar resulted in a rejection of the device. Centering forces were substantially stronger and more reliable at higher discharge rates.

The preceeding observations were followed up with a streamlined ABS 10 cm x 100 cm "fish" ballasted to about 5 kg net weight in water suspended by a line above the pool (See Fig. 6).

We expected to find the centering effects increasing in strength as the discharge orifice was approached. At mid depth moderate to weak centering forces held the fish inside the average plume. As the fish neared the discharge pipe the plume narrowed to a diameter comparable to the fish itself. In this situation momentum effects expelled the fish from the centre of the plume while Bernoulli effects held the fish against the plume as illustrated in Fig. 6.

These test observations were utilized in later work with reinforced flexible risers. The results are discussed at length in the next section.

3.5 Reinforced Fabric and Rigid Risers

The natural line of progression from the flexible risers was to a non-collapsing, steel reinforced fabric riser (in this case 5" (nominal diameter) domestic dryer vent hose). The following tests resulted in the most significant findings in the study and

in fact diverted us from testing any further generically different containment concepts. Our initial objective was to assess the flutter stability of reinforced risers. This line of investigation rapidly grew into a general investigation of the dynamics of gas lift behaviour in rigid or semi-rigid vertical pipes.

3.5.1 Reinforced Risers

Initial tests were carried out with 5" spiral reinforced vinyl dryer vent hose. This is a flexible expanding hose with a low collapse resistance. A length of hose was tethered to the discharge system with the top about 60 cm below the water surface (held by a float). The results were startling (VIDEO). Not only would the hose promptly centre itself directly over the discharge but it would also rapidly establish a high velocity lift which literally sucked in all of the discharge gas and water as well as a substantial amount of the surrounding water. This effect would operate even at the highest combined gas and water flow rates which we were able to generate. Further, the collection efficiency did not diminish when the riser was as much as 20 cm above the discharge orifice. The normal bubble observed at the free discharge orifice did not form under these circumstances. No flutter was in evidence, though we did observe some vertical vibration.

The pressure in the riser was evidently below hydrostatic pressure, as on one occasion at very high gas flow rates, we observed a progressive collapse of the riser from bottom to top. The cross-section was reduced to about 1/3 of the normal pipe

cross-section without in any way impairing the function of the device (VIDEO).

The observed centering effects were more due to the combined effects of buoyancy and the symmetry of the tethering arrangement than to any spectacular fluid forces. More realistic tests were carried out with a later generation of devices.

At this point it appeared that this device was a prime candidate for real subsea containment operations. Further testing was directed toward an exploration of its functional characteristics under a variety of conditions. Specifically we were interested in centering forces on a free floating device and a means of maximizing these forces, and as well, we wanted to establish the fluid flow velocities and the operational limits of the device.

3.5.2 Centering Effects

The reinforced riser discussed in 3.5.1 was ballasted with a 10 cm x 30 cm steel entry collar weighing about 7 kg in order to counteract the buoyancy effects in evidence when the hose was filled with fluids of lower density than water. The assembly was then suspended as shown in Fig. 7 near the discharge pipe.

In the first instance the ballast proved to be insufficient - the riser would alternately rise a few metres and then free fall to the length of its suspension. Significantly, the riser tended to stay centered in the plume during its unconstrained free fall. Ballast was increased to 12 kg by adding lead weights to the entry collar (VIDEO). At this weight the ballasting was sufficient under all circumstances.

Centering effects were observed with the riser suspended about 15 cm to one side of the discharge pipe. Weak hydrodynamic forces did pull the riser on centre into the plume (the plume was completely engulfed as soon as a small proportion of the gas entered the tube and the gas lift reached velocities which sucked in the entire discharge. With the plume completely engulfed, however, there were no centering forces and the riser would wander off the discharge pipe (VIDEO) in a cyclic pattern. It is significant to note that although centering forces ceased to be effective, neither were there any significant effects which would push the riser out of the plume - very little force would be required to insert or hold a riser on centre.

In an attempt to improve the self centering of the riser a steel cone was added to the riser. As illustrated in Fig. 8 the design concept was to use the momentum effects of the plume impinging on the cone in order to hold the riser on centre. The strategy appeared to be effective. The cone did not improve the containment performance of the riser (there may have been a slight degradation in performance).

The cone/riser was also tested with insufficient ballast to prevent lifting. As with the previous device the free falling device tended to descend through the centre of the plume.

Not all blowouts would be as convenient as a single vertical discharge pipe. Centering effects were assessed with a horizontal discharge pipe (Fig. 9). The results indicated that with a gas discharge only, the containment device centered itself normally and functioned as in previous cases. Discharge of water

(GOR<100:1) with the plume added significant momentum which tended to blow the device out of its optimal position.

3.5.3 Flow Rates

Attempts to measure fluid flow rates in the reinforced riser and to establish the vertical head which could be developed met with unforeseen results. The riser was connected to a valved drain line fitted with a pressure gauge as in Fig. 10. Water entrainment rates were to be estimated from the steady state tank losses.

Although fluids did pass through the system in this configuration the flow rates in the riser were an order of magnitude smaller than in previous tests. Most of the gas from the discharge pipe was spilled. Attempts to clear air locks or water locks were to no avail. Suspecting that the 50 cm head built into the measuring system was too much for the riser to cope with initially, we attached an open 2 metre length of hose to the top of the riser at water level. This time the fluid flow was increased to a modest rate, but was still far less than the flows previously observed. Most of the discharge gas was still being spilled.

It became clear at this point that the very effective riser performance observed in the initial tests was in fact a dynamic gas lift regime which "bootstrapped" itself to very high lift velocities only under certain conditions. A 90^{o} bend and a few metres of pipe was sufficient to prevent the development of this flow regime. Until a full flow developed, much of the discharge gas was spilled.

A better understanding of this bootstrapping phenomenon appears to be important. Evidently the fewer obstructions the more efficient the gas lift. The experimental system was changed to 10 cm straight rigid pipe with an open top a few cm below the water surface and a steel cone on the bottom for ballast. This device was suspended over the discharge system.

In this situation fluids (est. 30% water) were ejected from the riser to a maximum height of 3 metres above the water surface at the highest gas flow rates. The exit velocity of the fluid was apparently directly related to the gas injection rate (as well as to the hydrostatic head at the intake). An increase in gas flow rates apparently resulted in a proportional increase in fluid intake; flow velocities in the riser accelerated to accommodate the highest gas and water discharge rates which could be delivered.

The total liquids ejected from the 10 cm riser were estimated at 25000 l/hr water (approx. 1500 bbl/day). Judging from the observed behaviour of this system a 10 cm riser would handle a maximum flow rate of about 50000 l/hr liquids assuming a gas flow of about 100000 l/hr.

In an attempt to determine the limits of the gas lift handling capacity a 5 cm diameter riser was suspended over the discharge system. The top of the pipe cleared the water surface by about 1 metre. The device functioned as effectively as the 10 cm riser but we were not able to use gas flow rates above 17 l/sec because the fluids were exiting with sufficient velocity to reach electrical installations 8 metres above the tank. The

principle of operation was confirmed.

3.5.4 Gas Lift Dynamics

Gas lift pumps have been in extensive use for many decades. Time constraints precluded a thorough examination of available literature as a part of this report, however, a brief discussion of first principles is in order.

A simple phenomenological description of the device would be: an engine which converts the potential energy of gas released at some depth in a water column to kinetic energy in the riser with some energy losses due to turbulence and wall friction as graphically illustrated in Fig. 13. Increasing gas flow rates at a fixed depth and diameter will accelerate the flow velocity. At some velocity the turbulent energy losses and flow backpressures will reach values which begin to reduce liquid intake at the orifice. A more detailed analysis is presented in Appendix A.

Extrapolation of the test results to a large blowout (30 MCF/day in a hundred metres of water) may not be linear. Gas and condensate expansion during the vertical rise may alter the flow characteristics. Further the flow state may not be stable over a long vertical rise in a large diameter pipe. Slug or annular flow regimes may develop which could significantly change the backpressure in the riser. These are problems which are amenable to empirical investigation.

If the assumption of linear scale-up is reasonable, then it is estimated that a 30 MCF/day blowout with all of its liquids could be handled in a riser of less than 1 metre diameter

(assuming that the accompanying fluid intake would be about 10 MCF/day).

Evidently it would be desirable to reduce the intake of excess water - the liquid product from the riser described above would be 70% water. This might be achieved by throttling down the flow or by making a sealed connection to the wellhead. Since pressures are all negative in this situation, sealing may be feasible as discussed in the following section on operational applications.

4. OPERATIONAL APPLICATIONS

If the concepts developed in the preceeding work can be scaled up to the working depths and flow rates typical of offshore wells, the options for subsea containment operations become more flexible than prior thinking would indicate. So long as the appropriate design tables and computational formulae are available beforehand, a containment operation could probably be conducted in an ad hoc fashion using readily available materials and equipment for the collector/riser assembly. The concept of a complete prebuilt containment system does not appear to be necessary in view of the simplicity and size of the riser system.

Installation of the riser appears to be the greatest technical problem in any containment operation. Some of the containment proposals to date rely on the use of a "fireproof" tanker or platform with special adaptions for operation in or near a ourning gas boil. (This is not to minimize the real problems of anchoring the riser against currents and wave forces; handling of the product, etc. for any design concept).

The use of a high velocity gas lift riser could, in principle, scale down the proportions of a containment operation considerably. In particular, it may be feasible to install a sealed mechanically connected riser on a well head without deploying a vessel near the gas boil. The concept is presented schematically in Fig. 12. There may be operational or safety considerations to prevent this scheme from working but it is presented as one of a range of potential operational strategies.

The scheme presented involves the installation of a short length of riser by divers. Tank tests indicated that any length of riser should generate a high velocity gas lift; there appears to be no requirement that the lift reach the water surface. The valving integral to the depicted riser would have to be designed for streamline flow.

Positioning of the riser would be relatively simple and could be carried out by divers (at moderate depths) by the use of symmetrical tether lines and a remotely controlled buoyancy/ ballast system on the riser. Again, as observed in tank tests, once the riser comes within less than a pipe diameter of the "wellhead", suction effects will physically clamp it to the structure. At this stage the blowout plume would issue at the top of the riser only and divers could work at the wellhead to complete a mechanical connection and to seal the riser to the wellhead to prevent excessive water intake (which would incidently represent a hazard to the divers during this operation).

With mechanical connections completed the branch of the riser could be connected to a separately anchored marine riser which would be sized for a low backpressure to prevent undue stress on the wellhead connection.

The ensuing production operation would be routine except that the flow could not be shut off at any time.

In the case of a containment operation in ice covered waters the riser might deliver its product to an icebreaking spar/burner rather than to a tanker. It is worth noting that this spar could

be anchored and installed some distance from the wellhead if necessary.

5. CONCLUSIONS

On the basis of the concepts empirically assessed, it appears that the most effective subsea containment device is a simple vertical pipe without obstructions or attachments at the top or bottom. The gas lift principle (based on scaled down tests) is apparently energetic enough to completely contain a very large (30 MCF/day) blowout with a riser less than 1 metre in diameter. An understanding of the dynamic instabilities of open gas lift pumps is essential to the successful use of such a device.

Self centering effects are very weak in most situations, however, it is significant that containment devices will be weakly centered rather than violently rejected by a gas/liquid plume. Momentum effects from the rising fluids can be more effectively used than Bernoulli effects.

Fluttering problems with fabric risers can be overcome by choking. This procedure imposes pressure stress limitations on the riser and reduces the effective liquid capture unless the riser is of small diameter.

Reinforced fabric risers (non-collapsing) do not have flutter problems and can be used effectively as gas lifts.

6. RECOMMENDATIONS

The findings from this investigation indicate that subsea containment of a blowout might be operationally achieved without an inordinate investment in pre-built hardware, although that is not to say without preparation. We have found that a simple streamlined gas lift of small dimensions functions effectively in small scale empirical tests. That finding needs to be backed up by an engineering study of a full scale system as well as by further empirical testing. Several critical areas should be addressed.

1. The fluid dynamics of gas lift pumps should be investigated with particular attention given to back pressures and flow conditions for a range of gas liquid ratios and viscosities.

2. The possible effects of pipe length and diameter on flow conditions should be investigated.

3. The dynamics of gas lift pumps have been described in the literature. Likewise the effects of valves, bends and pipe roughness are well documented in terms of fluid backpressures. A study should be undertaken to delineate the range of conditions under which the desired high velocity flow will develop, the extent to which it can be throttled or controlled and the fundamental thermodynamics of the lift phenomenon in order to establish optimal riser design parameters. Gas and condensate expansion in a long vertical rise will alter the fluid density and possibly the flow characteristics. What, if any, effect will

vertical scale have on a gas lift?

4. Although much can be learned from analytical studies and laboratory testing, an operational test should be conducted if the results of analytical studies indicate the feasibility of a full scale operation.

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APPENDIX A

This particular gas lift operation can be approximated from simple thermodynamic or energy conservation arguments as an engine which converts the potential (buoyant) energy of gas injected at the bottom of the lift into kinetic energy in the rising fluids plus losses due to turbulence and wall friction.

$$E_p = E_k + \mathcal{F} \qquad (1)$$

E_p = potential energy (buoyant potential only)

E_k = kinetic energy of rising fluids

$\mathcal{F}$ = friction and turbulent dissipation

E_p can be approximated for the 3 cm rise in the test apparatus as

$$E_p = \int_{t_o}^{t_1} {}_w\, ghQ_G dt \qquad (2)$$

${}_w$ = density of water

g = gravitational constant

h = depth (length of the riser)

Q_G = gas flow rate

t = time

Gas expansion in the riser has been ignored since it is proportionately small in the specific case being considered.

$$E_k = \int_{t_o}^{t_1} 1/2\ m\ v^2 dt \qquad (3)$$

where

m = mass of rising fluid

v = velocity of rising fluid

$$v = \frac{Q_G + Q_w}{A} \qquad (4)$$

where

Q_w = water flow rate

A = cross sectional area of riser

$$m = {}_wQ_w + {}_GQ_G \qquad (5)$$

where

${}_G$ = gas density

If the gas density is considered to be negligible

$$m \quad {}_wQ_w \qquad (6)$$

Friction and turbulent dissipation can be set to zero for a first approximation for the flow velocities to be considered.

$$\mathcal{F} = \int f\ (v, Q_w, {}_w, Q_G, {}_G, \text{etc})\ dt \quad 0$$

Combining (3) to (6) generates a cubic in

$$Q_w{}^3 + 2Q_w{}^2\ Q_G + Q_w\ Q_G{}^2 = 2A^2gh\ \ Q_G \qquad (7)$$

which can be solved for Q_w given the gas injection rate, riser diameter and riser depth.

Calculating Q_w and exit velocity v for the two riser

diameters used in the test apparatus:

a) $A = 78\ cm^2$ for the 10 cm riser

$h = 3\ m$

$g = 9.8 m/sec^2$

$Q_G = 140\ l/sec$

$Q_W = 28\ l/sec$

giving a calculated exit velocity v of 5 m/sec.

The observed exit velocity was roughly 6 m/sec in the case. (Determined by estimating the height to which ejected fluids rose.)

b) $A = 20\ cm^2$ for the 5 cm riser

$h = 3\ cm$

$Q_G = 5.6\ l/sec$

$Q_W = 7.5\ l/sec$

and the calculated $v = 7 m/sec$

The observed exit velocity was about 15 m/sec: In this case the discrepancy appears to defy energy conservation laws. In all likelihood the velocity profile in this small riser was far from uniform as was assumed in the derivation of equation (7). If this were the case, we would have observed only the maximum velocity based on the height of the fluid column; the average exit velocity may have been made much smaller.

The limiting flow rate (see Fig. 13) for a 5 cm riser would probably be reached at or before $Q_G = 30\ l/sec$.

The calculated water intake (Q_W) at this gas flow is reduced to approximately 3 l/sec or a tenth of the gas injection rate. Friction and turbulent losses would probably reduce this number

somewhat further.

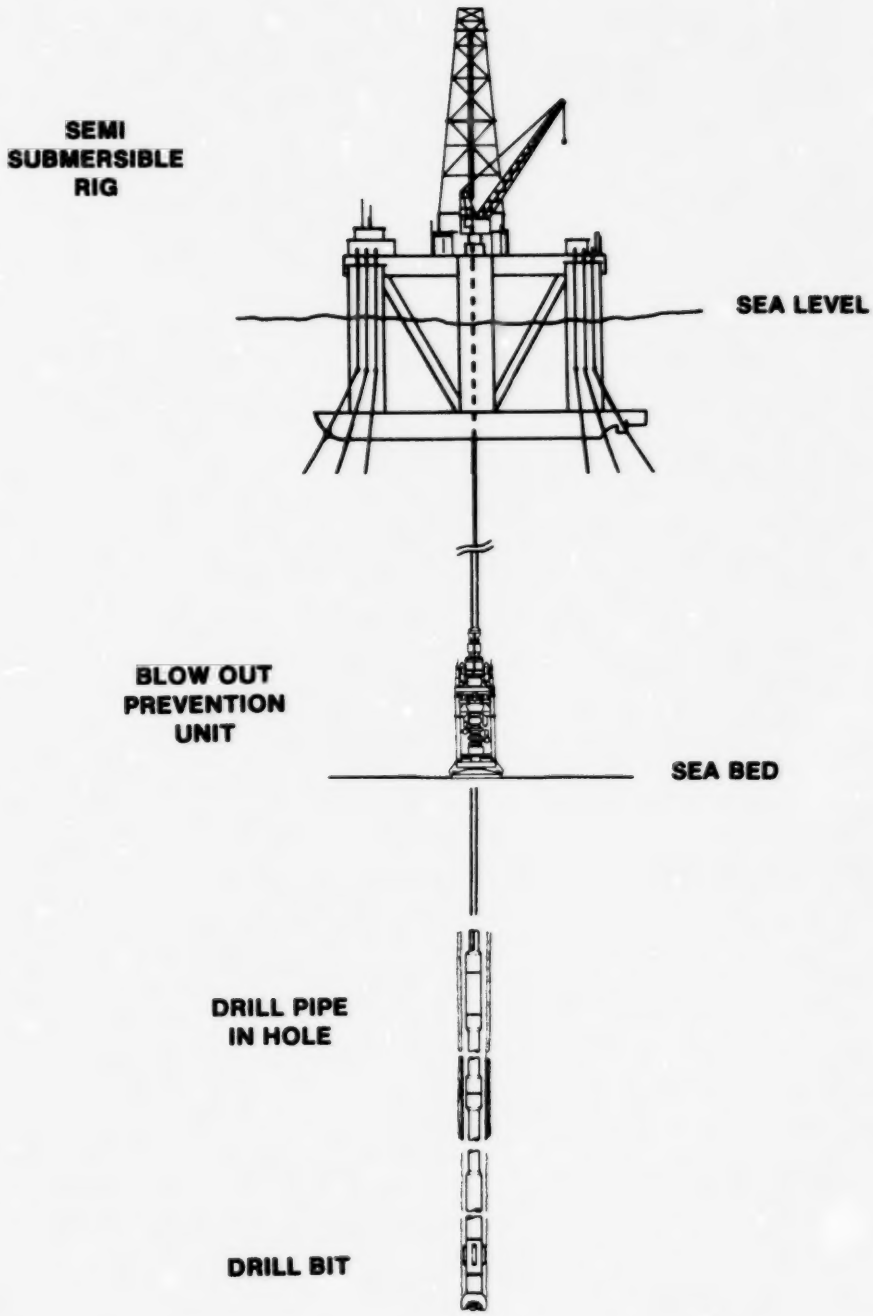
Projecting these calculations to a Q_G of 10^4 l/sec (30 MCF/day), a riser of approximately 1 m diameter should handle the gas flow plus about 10% liquids, if the diameter scale up is more or less linear and the depth (h) is held at 3 m. Increasing depth would increase the capacity due to an increase in available potential energy plus a reduction in intake gas volume. In order to carry out a scale up projection more accurately both gas expansion and friction losses must be taken into account.

APPENDIX B

Mobil

Harold Snyder. Linda
For your file

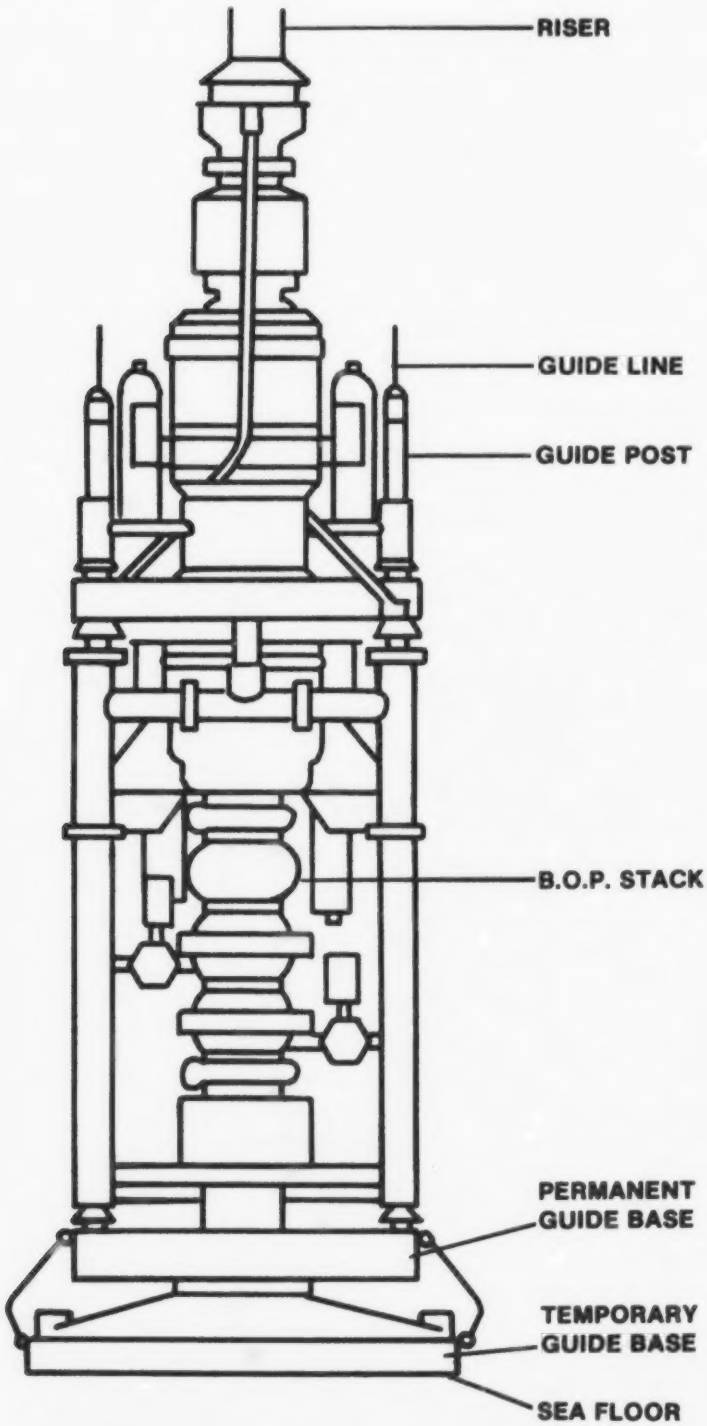
THE ATTACHED MATERIAL ACCOMPANIES
JIM MOUNTEER'S SPEECH



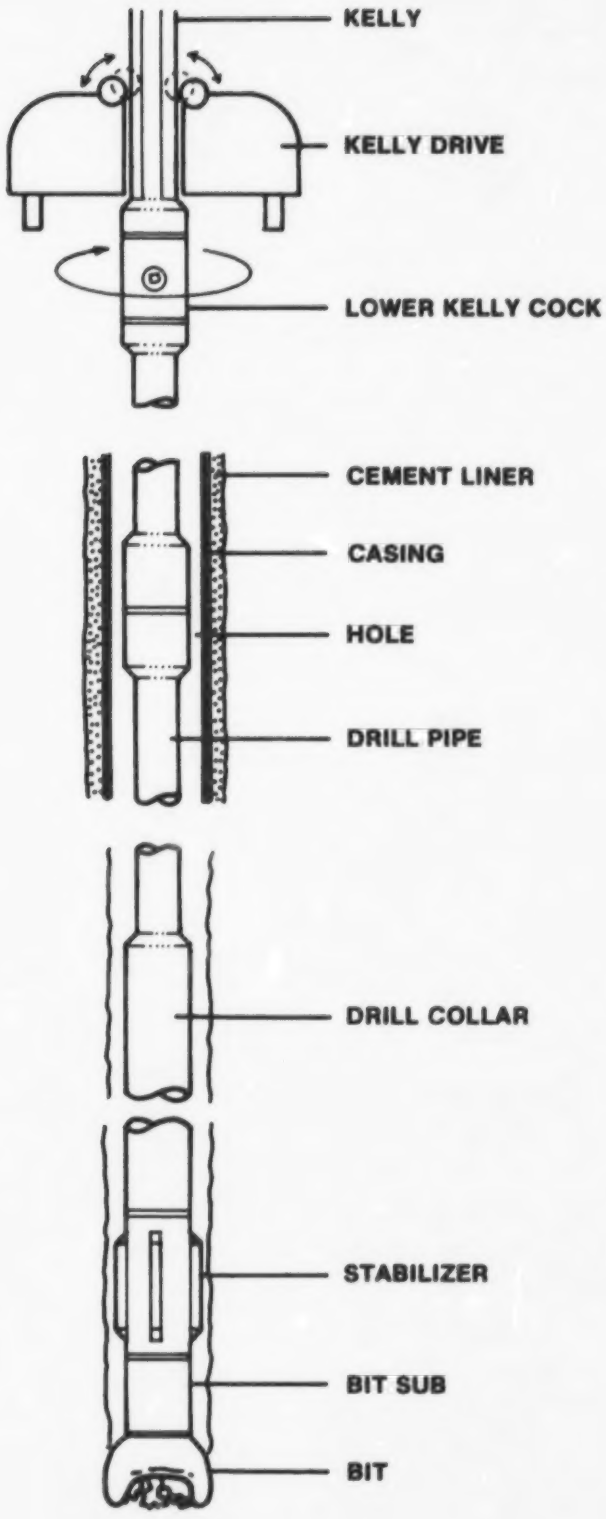
Not to scale

DRILLING FROM A SEMISUBMERSIBLE

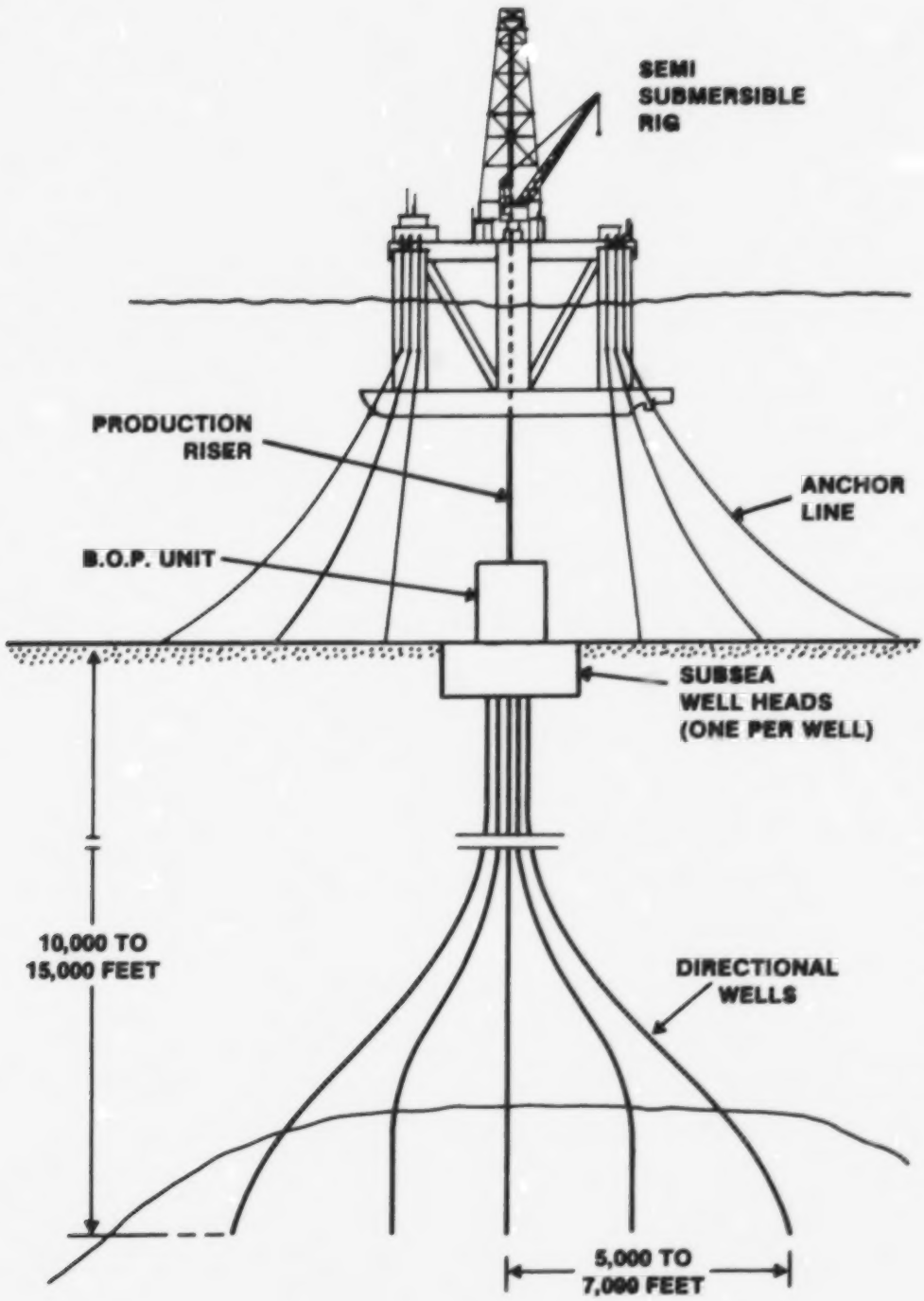
BLOW OUT PREVENTION
UNIT



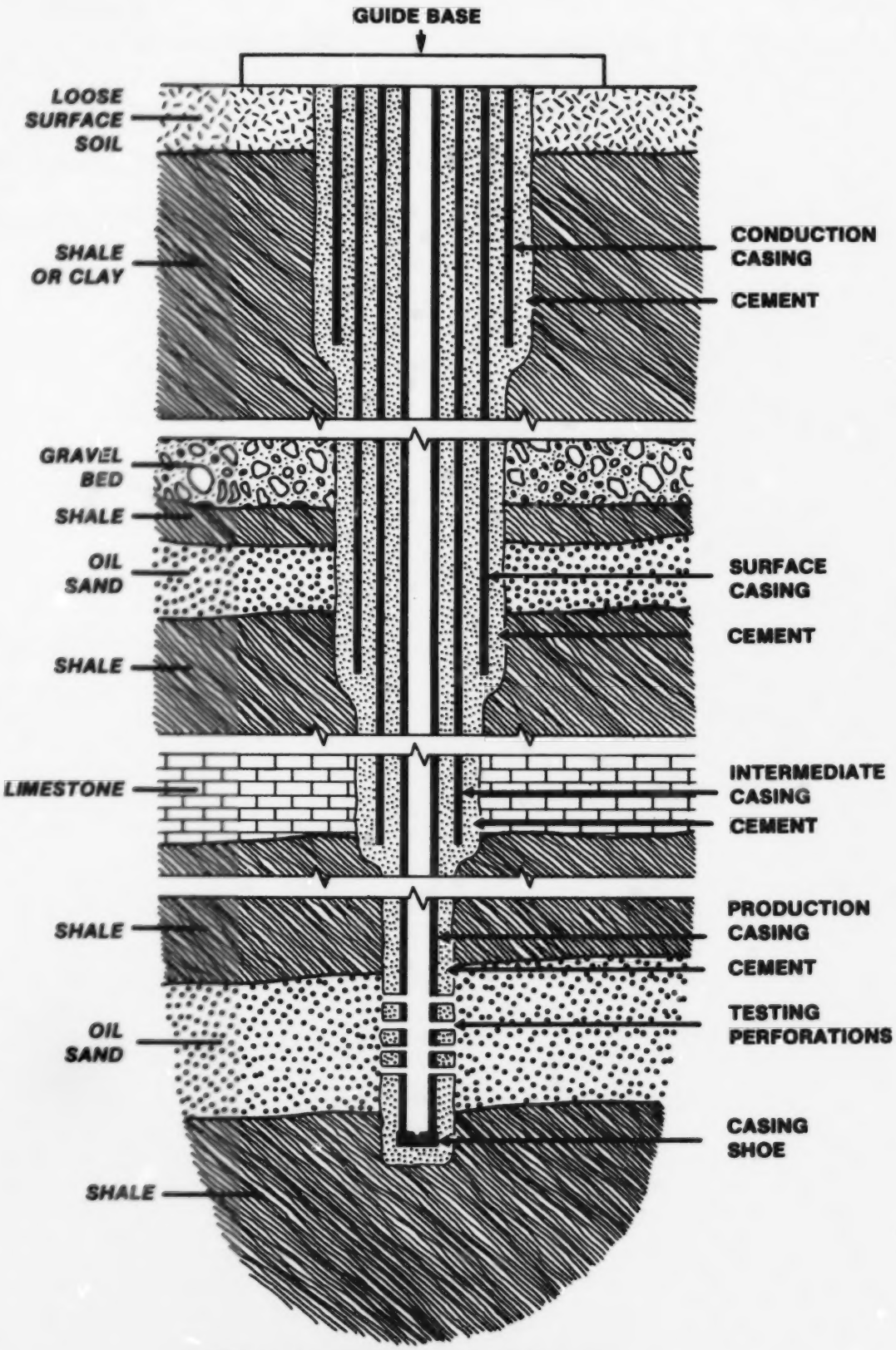
SAFETY EQUIPMENT USED TO PREVENT BLOWOUTS



TYPICAL EQUIPMENT USED IN THE DRILLING STRING



TYPICAL SEMISUBMERSIBLE DRILLING DEVELOPMENT WELLS



CROSS SECTION OF A TYPICAL WELL

E U 6 6 5 U

United States Patent [19]

Raseley et al.

[11] **4,214,883**

[45] **Jul. 29, 1980**

[54] **LIQUID-GAS SEPARATOR**

[75] Inventors: **LeRoy J. Raseley, Saylorsburg; Samuel J. Collier, Easton; Henry G. McCarty, Wind Gap, all of Pa.**

[73] Assignee: **Ecolaire Incorporated, Malvern, Pa.**

[21] Appl. No.: **11,479**

[22] Filed: **Feb. 12, 1979**

[51] Int. Cl.[2] **B01D 45/08**

[52] U.S. Cl. **55/426**; 55/465; 55/185

[58] Field of Search 55/186–188, 55/192, 193, 201, 202, 206, 426, 462, 464, 465, 185

[56] **References Cited**

U.S. PATENT DOCUMENTS

1,234,316	7/1917	Elliott	55/462
2,157,829	5/1939	Metzgar	55/465
2,742,976	4/1956	Toth et al.	55/455
3,306,009	2/1967	Cruse	55/201
3,477,208	11/1969	Keller, Sr.	55/218
3,795,088	3/1974	Esmond	55/206
3,926,594	12/1975	Seib et al.	55/465
4,002,432	1/1977	Brice et al.	55/188

Primary Examiner—David L. Lacey

Attorney, Agent, or Firm—Seidel, Gonda, Goldhammer & Panitch

[57] **ABSTRACT**

The separator includes a spherical housing containing therewithin a baffle which obstructs direct flow between an inlet and an outlet. The inlet and outlet support the baffle which is comprised of two modular members connected end-to-end.

9 Claims, 5 Drawing Figures

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JUN 20 1981
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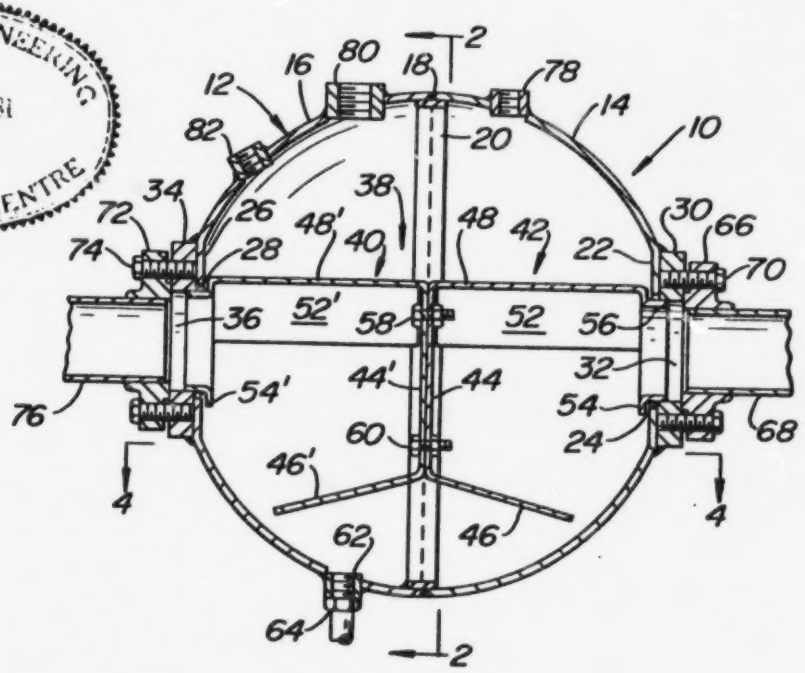


LIQUID-GAS SEPARATOR

BACKGROUND

Liquid gas separators having spherical housings are known in the prior art. See U.S. Pat. Nos. 2,742,976 and 3,477,208. It is also known to suspend the baffle within the housing as taught by U.S. Pat. Nos. 1,234,316 and 3,916,594.

The customary design for a baffle of the type involved herein is to fabricate the same from flat plate or to cut the same from channel-shaped metal. I have found that various advantages can be attained if the separator is designed in a manner so as to eliminate machining and welds in connection with the baffle.

SUMMARY OF THE INVENTION

The liquid-gas separator of the present invention includes a generally spherical housing having a liquid-gas inlet and a gas outlet. The housing also includes a liquid outlet below the elevation of the gas outlet. A baffle is provided in the housing for obstructing direct flow from the liquid gas inlet to the gas outlet. The baffle is supported within the housing at one end by the liquid-gas inlet and at its other end by the gas outlet. The baffle includes two modular members connected together end-to-end.

It is an object of the present invention to provide a liquid-gas separator which simplifies the design of a baffle, simplies assembly of the separator, and minimizes the number of inventory components while at the same time eliminating the need for machining or welding in connection with the baffle.

Other objects will appear hereinafter.

For the purpose of illustrating the invention, there is shown in the drawings a form which is presently preferred; it being understood, however, that this invention is not limited to the precise arrangements and instrumentalities shown.

FIG. 1 is a longitudinal sectional view through a liquid-gas separator in accordance with the present invention.

FIG. 2 is a sectional view taken along the line 2—2 in FIG. 1.

FIG. 3 is an exploded perspective view of the present invention.

FIG. 4 is a sectional view taken along the line 4—4 in FIG. 1.

FIG. 5 is a sectional view of one end of another embodiment.

Referring to the drawings in detail, wherein like numerals indicate like elements, there is shown a liquid-gas separator in accordance with the present invention designated generally as 10.

The separator 10 includes a generally spherical housing 12 made from metal of a suitable thickness. A spherical design enables the thickness of the housing to be much less than it would be for a cylindrical housing at an equal design pressure. The housing 12 is comprised of modules 14 and 16 which are generally semi-spherical and welded together by weld 18. A ring 20 is tack welded to one of the modules such as module 16. Module 14 telescopes over the ring whereby the weld 18 can penetrate the entire wall thickness of the modules 14, 16.

Module 14 has a flat portion 22 containing an opening 24. Similarly, module 16 has a flat portion 26 containing an opening 28. A plate 30 is welded to the flat portion

22. Plate 30 has a bore 32 which is smaller than and coaxial with the opening 24. As shown in FIG. 1, plate 30 is thicker than the material of the module 14. A plate 34 is similarly welded to the flat portion 26. Plate 34 has a bore 36 coaxial with and smaller than the opening 28.

A baffle designated generally as 38 is suspended within the housing 12. The baffle 38 is comprised of modules 40 and 42 which are identical. Each of the modules 40, 42 is blanked and stamped from a single piece of material such as carbon steel or stainless steel. The modules 40, 42 are identical and connected end-to-end. Since the modules 40, 42 are identical, only module 42 will be described in detail with corresponding primed numerals applied to module 40.

The module 42 includes a transverse wall 44 which interrupts direct flow from the bore 32 to the bore 36. At its lower end, wall 44 has an angularly disposed and downwardly extending lip 46. As shown more clearly in FIG. 2, the side edges of wall 44 and lip 46 are curved so as to mate with the inner periphery of the ring 20 and the inner periphery of modules 14 and 16. See FIGS. 3 and 4.

At its central portion, along the upper edge of the wall 44, there is provided a horizontally disposed top wall 48 which extends toward the flat portion 22. The top wall 48 has downwardly and angularly extending flanges 50, 52 along its side edges. The flanges 50, 52 converge upwardly. See FIG. 2.

The end of top wall 48 remote from the wall 44 is enlarged so as to define a rectangular end wall 54. Wall 54 is parallel to wall 44 and perpendicular to the top wall 48. End wall 54 has a boss 56 projecting therefrom. The diameter of boss 56 is chosen such that it may telescope into the bore 32 and thereby suspend one end of the baffle 38. The other end of the baffle 38 is supported in a similar manner by bore 36. The baffle 38 is assembled by joining the modules 40, 42 end-to-end using fasteners 58, 60. The baffle 38 is then inserted into the housing 12 before the weld 18 is applied.

An opening 62 is provided on the lower portion of the housing 12 beneath the baffle 38 to facilitate drainage of liquid. A conduit 64 is connected to the opening 62 to facilitate continuous draining of liquid. A flange 66 on a conduit 68 is releasably connected to the ring 30 by way of fasteners 70. A flange 72 on a conduit 76 is releasably connected to the plate 34 by fasteners 74. The conduits 68 and 76 is coaxial. An advantage of the construction of the present invention is that either conduit 68 or 76 could be the inlet with the other being the outlet.

The housing 12 is preferably but optionally provided with a plurality of couplings that have been tapped with internal threads. Thus, coupling 78 may be provided and a pressure gauge may be connected thereto. A coupling 80 may be provided with a pressure relief valve connected thereto to relieve any excess pressure within the housing 12. Also, a coupling 82 may be provided for receiving a temperature measuring device such as a thermocouple. The couplings 78, 80 and 82 are optional and when provided are welded at their periphery to holes in the modules 14 and 16.

Assuming that conduit 68 is an inlet conduit, a gas stream containing undesired liquid is introduced into housing 12. The stream impinges on wall 44. The liquid separates from the gas stream and flows down lip 46 and accumulates in housing 12 below the baffle 38 and discharges via conduit 64. The lips 46, 46' on modules 40,

42 define a tortuous path so as to minimize any tendency of accumulated liquid becoming airborne again.

The gas stream flows outwardly beyond the lower edges of flanges 50, 52, then upwardly over the wall 44, then downwardly under the lower edges of the flanges 50', 52' on module 40 and then out through bore 36 to conduit 76.

In FIG. 5, there is shown one end portion of another embodiment wherein separator 90 is identical with separator 10 except as is set forth hereinafter. In separator 90, each of the mating modules 92 lacks a flat portion such as the flat portions 22, 26. Instead, a plate 84 (comparable to plate 30) is welded at its periphery to module 92 around a hole therein. Plate 84 is substantially thicker than the wall thickness of module 92 so as to reinforce module 82. Plate 84 has a bore 86 for receiving and supporting one end of module 88. Thus, it will be noted that this embodiment provides economy in eliminating the steps necessary to provide flat portions 22, 26.

The present invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof and, accordingly, reference should be made to the appended claims, rather than to the foregoing specification, as indicating the scope of the invention.

I claim:

1. A liquid gas separator comprising a generally spherical housing having a liquid-gas inlet opening coaxial with a gas outlet opening, a liquid outlet drain in said housing below the elevation of said openings, said housing having flat portions at diametrically opposite locations, each of said openings being in one of said flat portions, a discrete plate welded to the outer peripheral surface of said housing at each of said flat portions, each plate having a bore coaxial with the opening on the adjacent flat portion, a baffle in said housing, said baffle being suspended within said housing by said openings, said baffle including two identical modules, means connecting said modules end-to-end and said modules having side edges mating with juxtaposed surfaces in said housing.

2. A separator in accordance with claim 1 wherein each each of said modules includes a transverse wall interrupting direct flow between said openings, the transverse walls being at one end of the respective modules and being releasably coupled together by said connecting means.

3. A separator in accordance with claim 2 wherein each each of said modules includes an annular boss extending into one of said aligned openings, each of said annular bosses being connected to the transverse wall on its associated module by way of a top wall connected to the upper edge of the transverse wall associated therewith.

4. A separator in accordance with claim 1 wherein each each of said plates has a plurality of exposed tapped holes for connecting a flanged conduit thereto.

5. A liquid-gas separator comprising a generally spherical housing having a liquid-gas inlet, said housing having a gas outlet and a liquid outlet, the liquid outlet being below the elevation of the gas outlet, a baffle in said housing and obstructing direct flow from said liquid-gas inlet to said gas outlet, said baffle having one end supported by said liquid-gas inlet and its other end supported by said gas outlet, said baffle including two modular members, means connecting said members end-to-end, each modular member of said baffle including a transverse wall having an angularly disposed lip at its lower end, said lips converging upwardly toward an imaginary plane between the transverse walls of said modular members to define a tortuous path so as to minimize any tendency of accumulated liquid becoming airborne again, and said transverse walls being generally perpendicular to the axis of said inlet with arcuate ends mating with the interior surface of said spherical housing.

6. A separator in accordance with claim 5 including a first plate welded to said housing and containing the liquid-gas inlet, a second plate welded to said housing and containing the gas outlet, said plates being thicker than the wall thickness of said housing.

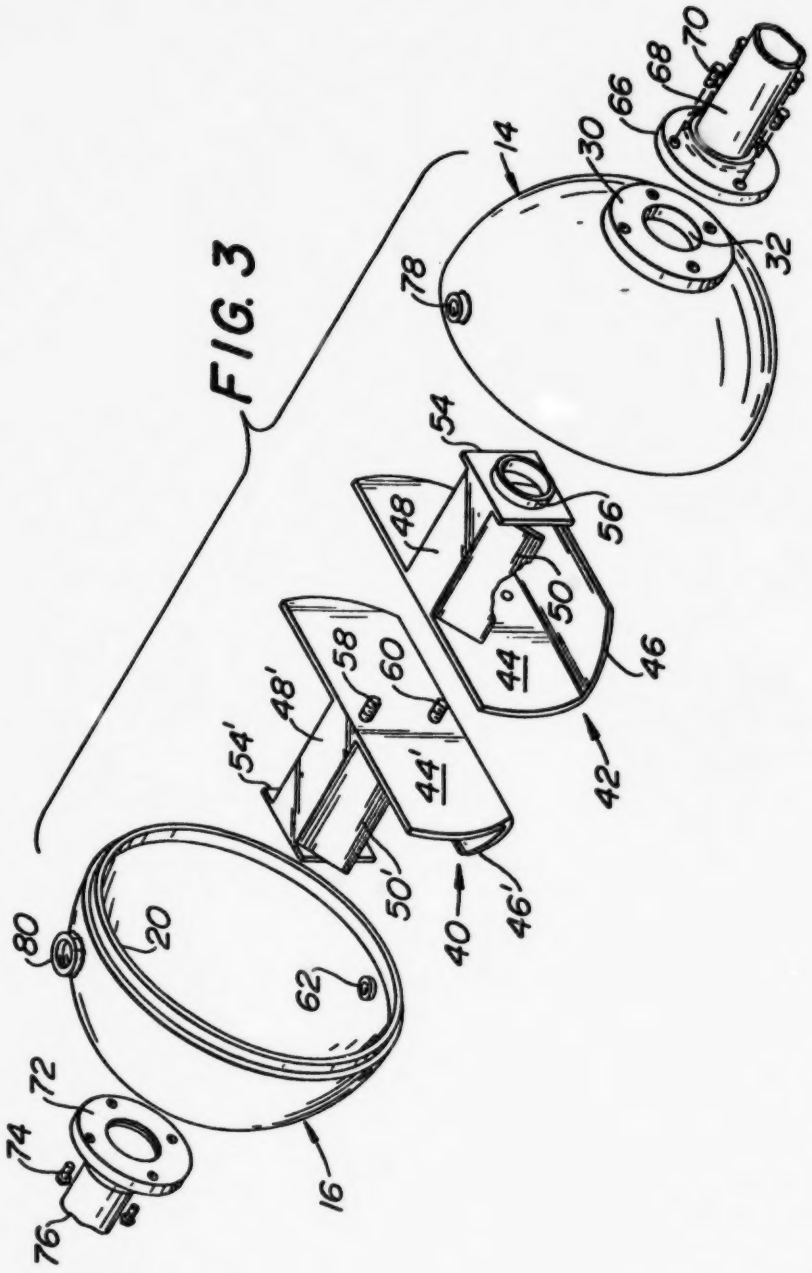
7. A separator in accordance with claim 5 wherein said connecting means secures said transverse walls together, and further comprising a top wall connected to the upper end of each of said transverse walls, one of said top walls extending toward said inlet and having side flanges extending downwardly from the side edges thereof, each top wall having an annular portion which is coaxial with and supported by one of said inlet and said gas outlet.

8. A separator in accordance with claim 5 wherein said spherical housing has a flat portion at opposite regions thereon, one of said flat portions containing said inlet, the other of said flat portions containing said gas outlet, a discrete of said plates welded to each of said flat portions, each of said plates having a thickness substantially greater than the thickness of the wall defining said spherical housing, each of said plates having a bore coaxial with the opening in the juxtaposed flat portion.

9. A separator in accordance with claim 8 wherein each of said plate is provided with threaded holes for receiving a fastener so that each of said plate may be joined to a flange on a conduit.

* * * * *

FIG. 3


70
68
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14
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16

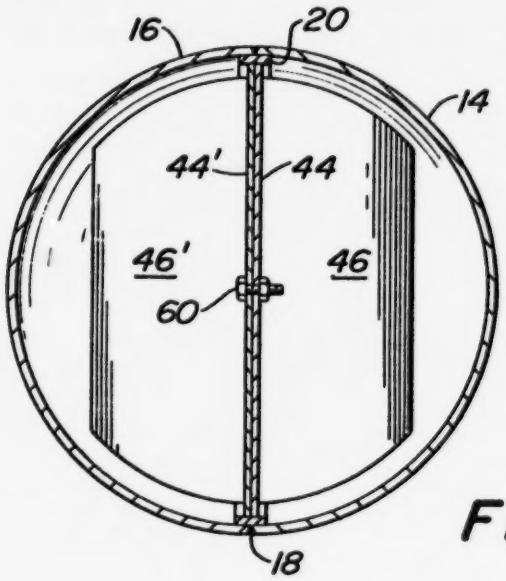

FIG. 4

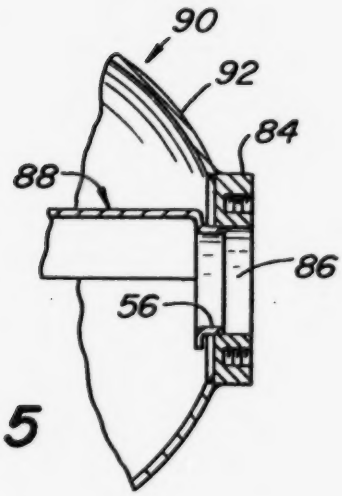

FIG. 5

EU6631

United States Patent [19]

Acker

[11] **4,231,767**

[45] **Nov. 4, 1980**

[54] **LIQUID-GAS SEPARATOR APPARATUS**

[75] Inventor: **Roy M. Acker, Los Angeles, Calif.**

[73] Assignee: **TRW Inc., Cleveland, Ohio**

[21] Appl. No.: **953,598**

[22] Filed: **Oct. 23, 1978**

[51] **Int. Cl.**³ **B01D 19/00**

[52] **U.S. Cl.** **55/186**; 55/521; 166/105.5

[58] **Field of Search** 55/159, 160, 210, 213, 55/314, 521, 525, 185–188; 166/105.5, 105.6, 205, 230; 210/120, 130, 131

[56] **References Cited**

U.S. PATENT DOCUMENTS

1,572,333	2/1926	Taylor	166/105.6
1,578,720	3/1926	Derby	166/105.5
1,611,206	12/1926	Larc	166/205
1,915,136	6/1933	Share	166/230
2,096,484	10/1937	Farmer	55/159
2,104,339	1/1938	Arutunoff	166/105.5 X
2,823,760	2/1958	Andersen	55/313
2,877,852	3/1959	Bashara	166/230 X
3,386,230	6/1968	Riesberg et al.	55/337
3,394,533	7/1968	Li et al.	55/337
3,413,778	12/1968	Lavery et al.	55/186
3,448,862	6/1969	Kudlaty	210/489
3,492,793	2/1970	Bhuta et al.	55/159
3,664,093	5/1972	Murdock	55/174
3,881,870	5/1975	Hatfield	55/521 X
3,892,547	7/1975	Tucker	55/178
3,893,925	7/1975	Jones	210/166
3,933,448	1/1976	Di Peri	55/159
4,050,237	9/1977	Salz et al.	55/486 X

Primary Examiner—John Adee

Attorney, Agent, or Firm—Shapiro and Shapiro

[57] **ABSTRACT**

A downhole liquid-gas separator for use with a submergible pump employs an inverted conical, convoluted, fine-mesh screen in a tubular housing. The convolutions form grooves extending upwardly along the screen. A liquid-gas mixture enters the housing near the lower, apex end of the screen. The screen mesh size is selected so that liquid is pumped through the screen and continues to flow upwardly through the housing, while gas bubbles rise along the exterior of the screen and are vented from the housing. The gas bubbles channel into the troughs of the screen grooves, leaving the peak regions of the convolutions free for the passage of liquid. A relief valve arrangement bypasses the screen when it becomes clogged, and permits the liquid-gas mixture to flow upwardly through the housing.

9 Claims, 4 Drawing Figures

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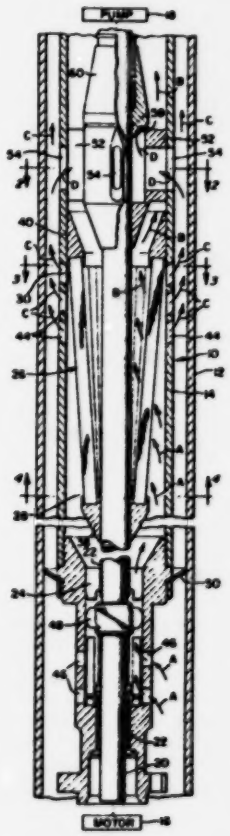

LIQUID-GAS SEPARATOR APPARATUS

BACKGROUND OF THE INVENTION

This invention relates to liquid-gas separators and more particularly to downhole liquid-gas separators used in conjunction with submergible pumps.

Liquid-gas separators are used downhole in oil-producing wells to separate gas from crude oil before the oil enters the downhole pump. See, for example, U.S. Pat. Nos. 2,104,339 and 2,969,742, both assigned to the same assignee as the present invention. Any gas present in the oil supplied to the pump tends to reduce the volumetric efficiency of the pump. Thus an effective liquid-gas separator enables the pumping of more oil. The present invention is directed to an improved liquid-gas separator and employs a unique fine mesh screen structure to provide better separation of gas from liquid than has been possible with comparable separators known heretofore.

The prior art is replete with separators or filters employing screens or other porous structures. U.S. Pat. No. 3,933,448 discloses a device employing a convoluted screen partition which passes liquid, but not gas. U.S. Pat. No. 3,394,533 discloses a device employing a conical screen (with its axis horizontal) which passes gas but not liquid. U.S. Pat. No. 3,893,925 discloses a device employing an upright perforated fluted conical structure for separating oil from water. See also U.S. Pat. Nos. 4,050,237; 3,386,230; 3,413,778; 3,492,793; 2,823,760; 3,664,093; 3,892,547; 1,711,779; 3,448,862; 621,998; 1,071,328; 2,096,484; 2,170,074; 2,191,052; 2,717,148; 2,749,265; and 3,159,310. Despite the proliferation of prior art, a need has remained for a superior device for separating liquid such as crude oil from gas in a downhole environment.

BRIEF DESCRIPTION OF THE INVENTION

Briefly stated, a preferred embodiment of the present invention employs an inverted conical, convoluted, fine-mesh screen to separate gas from liquid. The screen passes the liquid but not the gas. Gas bubbles channel into the troughs of upwardly extending screen grooves, leaving peak regions of the convolutions free for the passage of liquid. The screen may be bypassed automatically if it becomes blocked.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be further described in conjunction with the accompanying drawings, which illustrate a preferred and exemplary embodiment, and wherein:

FIG. 1 is a contracted longitudinal sectional view illustrating the apparatus of the invention installed in a well; and

FIGS. 2, 3 and 4 are transverse sectional views taken along lines 2—2, 3—3, and 4—4, respectively.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 illustrates liquid-gas separator apparatus 10 of the invention installed downhole in a well, the cylindrical casing of which is shown at 12. The apparatus of the invention comprises a tubular (preferably cylindrical) housing 14 extending longitudinally within and spaced from the well casing 12. In the embodiment illustrated, the lower end of the housing 14 is connected to the housing of an electric motor 16 (shown diagrammatically), and the upper end of housing 14 is connected to the housing of a submergible pump 18 (shown diagrammatically). An appropriate motor and pump unit (including a protector which may be interposed between the motor and the separator) is disclosed in U.S. Pat. No. 2,270,666, assigned to the same assignee as the present invention. A drive shaft 20 extends from the motor to the pump along the axis of housing 14. Shaft 20 may be supported in the housing by means of sleeves 22 mounted on end walls of the housing and mounted intermediate the end walls by spiders 24.

The invention employs a liquid-gas separator screen 26 forming an inverted generally conical structure that tapers from a lower, apex end 28 to an upper, base end 30. The screen is convoluted or fluted to provide successive peaks 32 and troughs 34 defining grooves 36 extending upwardly along the conical screen. Lower end 28 of the screen may be embedded in a support 38 mounted on a sleeve 22, while the upper end 30 of the screen may be embedded in a support 40 sealed to the sidewall of housing 14. Supports 38 and 40 may comprise conventional potting material, for example. Gas vents 44 are provided through the side-wall of housing 14 just upstream of the upper end 30 of screen 26. Inlets 46 are provided at the lower end of the housing to permit ambient well fluid, which will be referred to as a liquid-gas mixture, to enter the housing 14. An inducer 48, such as an impeller mounted on shaft 20 downstream of inlets 46, is preferably employed to add to the net positive suction head and thereby limit the amount of cavitation at the main pump 18. A barrier 50 is preferably provided to seal the space between the housing 14 and the casing 12 at the lower end of the housing, so that the liquid-gas mixture in the casing is constrained to enter inlets 46.

A bypass arrangement is provided to permit the liquid-gas mixture to flow through the housing 14 in the event that the screen becomes clogged or blocked. In the form shown the bypass arrangement comprises a cruciform spider structure downstream of screen 26 and including hollow arms 52 providing ducts which extend from inlet ports 54 through the sidewall of housing 14 to a central chamber 56 in the housing. The upper end of chamber 56 has an outlet opening 58 that is normally closed by a relief valve 60, such as a conventional spring-biased poppet.

The invention operates generally in the following manner. The liquid-gas mixture enters the housing 14 and approaches the screen 26 as indicated by arrows A. Liquid passes through the screen and flows upwardly through the housing 14 as indicated by arrows B, past the arms 52 of the cruciform structure to the inlet of pump 18. The gas bubbles pass upwardly along the exterior of screen 26, exit from the housing 14 via vents 44, and move upwardly in the space between housing 14 and casing 12, as indicated by arrows C. If the screen becomes overloaded with solid particles, that is, blocked or clogged, the pressure differential on the relief valve 60, such as 2–5 psi, will be sufficient to open the valve, permitting the liquid-gas mixture to bypass the screen and flow along the exterior of the screen, out of vents 44, through the hollow arms 52 of the cruciform structure, and out of opening 58 of the central chamber 56 and through housing 14 to the pump, as indicated by arrows D. By providing a suitable reverse flow arrangement, as, for example, in U.S. Pat. No. 3,807,894, assigned to the same assignee as the present invention, the screen may be flushed when the pump is

shut down, so that the relief valve may then shut again and the screen may again function as a liquid-gas separator.

The liquid-gas separator of the invention operates upon the principle that gas bubbles are inhibited from passing through a fine mesh screen by the surface tension effects of the liquid, but the liquid passes through the screen. Gas bubbles which collect on the screen surface merge to form bubbles which have sufficient buoyancy to overcome the surface tension force and which float upwards and out of the separator into the space between the housing **14** and the well casing **12**, and then to the surface. Screens can be purchased with a desired bubble point rating, which is the differential pressure across the screen at which bubbles break free of the surface tension and gas penetrates the screen (for a standard test liquid). The greatest resistance to bubble penetration would be provided by the finest mesh screens. Unfortunately, the finest mesh screens also have the greatest resistance to liquid flow through the screen, and the liquid must penetrate the screen to be separated from the gas. Moreover, screen choice cannot be made entirely on the basis of the ratio of bubble point pressure to flow resistance factor, because there are other sources of pressure differential acting on the screen which must be considered. For example, there may be places on the screen where the pressure differs by an amount equal to the velocity head because of the stagnant fluid on one side and the moving fluid on the other. Vibration of the separator can also cause pressure differential across the screen. Thus the optimum screen is a weighted choice, considering the various conflicting factors.

The screen preferably employed in the present invention to separate gas and crude oil is a square mesh stainless steel screen having 230 0.0014 inch diameter wires per inch with a mesh opening of 0.0029 inch and 46% open area. To assist the fine mesh screen **26** in withstanding the applied pressure, a heavier screen (not shown), such as a square mesh screen with 14 0.009-inch diameter wires per inch, may be employed to back up the fine mesh screen. It may be desirable to weld or braze the exposed screen edges to a 0.25-inch wide strip of stainless steel shim stock, for example, to prevent unraveling of the screen material. The fine mesh screen **26** may have an area of about 128 sq. in. and a length of about 9 inches with grooves **36** about ¼ inch in depth at the apex end and with successive troughs **34** circumferentially spaced by 30° at the apex end. Such a screen has the capability of allowing a flow of 4.67 GPM/sq. in., which is far in excess of the 0.312 GPM/sq. in. theoretically required for a pump flow of 40 GPM.

Bubbles attached to the screen and sand particles embedded in the screen reduce the available flow area and increase the pressure drop due to the flow. The effect of sand will be cumulative, so that a large amount of excess area is desirable. Bubbles floating upward near the screen tend to be driven into the screen by the liquid flow, increasing the screen area which is restricted. The screen may also be damaged in a manner which opens up some pores, allowing gas to flow through the screen at less than the bubble point pressure. An excess of screen area minimizes the pressure differential and makes less likely the passage of gas through the screen.

Bubbles blockage of the screen is a significant problem in providing a satisfactory liquid-gas separator. As bubbles flow upwardly past the screen, the bubbles have a vertical velocity equal to the liquid velocity plus the bubble rise velocity. As liquid flows through the screen, the velocity of the remaining liquid is slowed, thereby reducing the bubble velocity. With the same volume of bubbles, a greater cross-sectional area is required for the bubbles.

The convoluted, inverted conical screen employed in the invention performs synergistically to solve this problem. The convolutions provide increased screen area, of course, and the effective area of the screen increases as fluid flows upwardly toward the base of the screen. Moreover, the upward movement of the bubbles is directed along the grooves **36** and the bubbles channel into the troughs **34** of the upwardly extending grooves by virtue of the slope of the inverted conical surface, leaving the convex portions at the peaks of the screen folds open for liquid passage. The convoluted screen thus not only provides additional surface area but also provides a structure in which bubble blockage of the screen is reduced. In comparison, a simple conical screen without convolutions would separate gas, but would become saturated and pass gas at a lower percentage of gas than the convoluted inverted conical screen of the invention.

One design concern is the radius of the concave troughs of the convolutions. It is preferred that this radius be made greater than the effective radius of the breakaway bubble. Otherwise, the surface tension forces on the bubble may be augmented by the greater effective perimeter enveloping the bubble and cause the bubble to grow to a larger diameter before breaking away. It has been determined that the larger bubbles are not spherical and have a higher drag coefficient than that for the equivalent sphere, which results in a slower rise velocity, increased bubble blockage of the screen and a greater required area. For crude oil, a bubble size between 0.127 and 0.180 inch diameter at breakaway is indicated. The radius of the concave trough portions of the convolutions of the screen should preferably be at least half of these values. In practice, a radius of 0.09 inch appears to be satisfactory. The same radius may be used for the convex peaks of the convolutions.

While a preferred embodiment of the invention has been shown and described, it will be apparent to those skilled in the art that changes can be made in this embodiment without departing from the principles and spirit of the invention, the scope of which is defined in the appended claims.

I claim:

1. Liquid-gas separator apparatus comprising a tubular housing adapted to be placed upright in a well, an inverted generally conical, convoluted screen in said housing with its axis extending longitudinally of the housing, the screen convolutions having successive peaks and troughs defining grooves extending along the screen from a lower, apex region of the screen to an upper, base region of the screen, the apex region of the screen being spaced from a sidewall of the housing and the base region of the screen being sealed to the sidewall of the housing, inlet means for directing a liquid-gas mixture into the housing near the apex region of the screen and for constraining the mixture to pass upwardly along the exterior of the screen, and vent means near the base region of the screen for venting gas from the housing, the mesh size of the screen being predetermined so that liquid passes through the screen and gas passes along the exterior of the screen, especially in the grooves, and is vented through the vent means.

2. Apparatus in accordance with claim 1, wherein the housing is within and spaced from a tubular well casing and the vent means provides a flow path from within the housing to the space between the housing and the casing.

3. Apparatus in accordance with claim 2, further comprising barrier means between the housing and the casing downstream of the inlet means so that the liquid-gas mixture is constrained to enter the inlet means.

4. Apparatus in accordance with claim 1, further comprising means in the housing for inducing a flow of the liquid-gas mixture toward the apex region of the screen.

5. Apparatus in accordance with claim 1, wherein a downstream end of the housing is connected to the inlet of a pump for pumping liquid through the housing.

6. Apparatus in accordance with claim 5, wherein an upstream end of the housing is connected to a motor, and a shaft for driving the pump extends from the motor through the housing to the pump.

7. Apparatus in accordance with claim 1, further comprising bypass means including duct means downstream of the screen for admitting fluid from the exterior of said housing to a chamber in the housing, the chamber having an outlet to the housing downstream of the screen, and pressure relief valve means for closing said outlet until a predetermined pressure differential exists across said valve means when the screen becomes clogged.

8. Apparatus in accordance with claim 7, wherein said duct means comprises a spider structure having a plurality of hollow arms extending inwardly of the housing to said chamber from inlet ports through the housing wall.

9. Liquid-gas separator apparatus comprising a housing having an upwardly extending wall, a convoluted screen in said housing having an interior surface and an exterior surface, the exterior surface facing said wall, said screen having a lower end spaced from said wall, said screen extending upwardly and outwardly from said lower end toward said wall and having an upper end sealed to said wall, the housing having a liquid flow path which extends upwardly from the interior surface of said screen, the screen convolutions having successive peaks and troughs defining grooves extending upwardly along the screen from the lower end of the screen to the upper end of the screen, inlet means near the lower end of the screen for directing a liquid-gas mixture into the space between said screen and said wall and for constraining said mixture to flow upwardly along the exterior surface of the screen, and vent means near the upper end of the screen for venting gas from the space between the screen and said wall, the mesh size of the screen being predetermined so that liquid passes through the screen and gas passes along the exterior surface of the screen, especially in the grooves, and is vented through the vent means.

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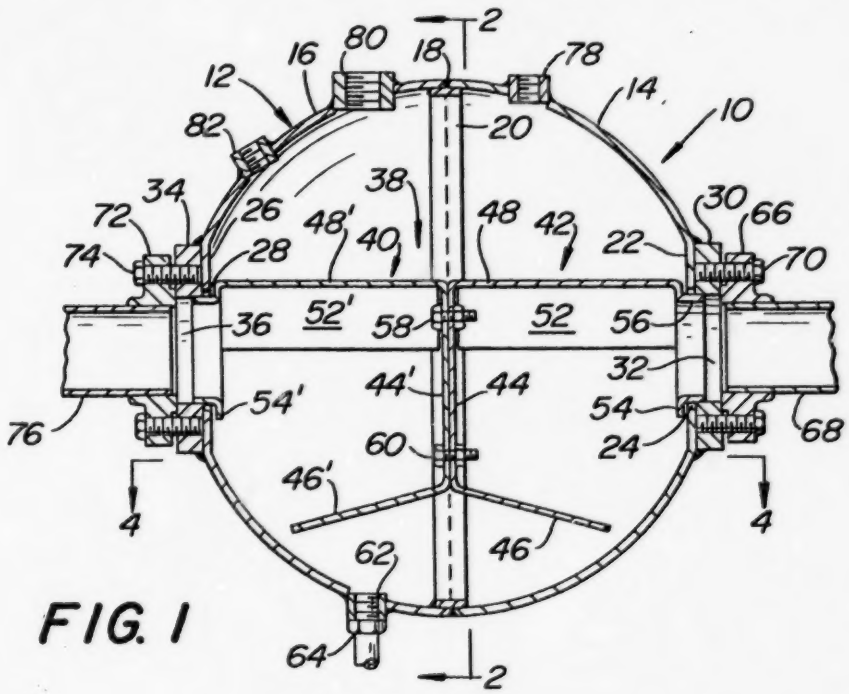
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FIG. 1

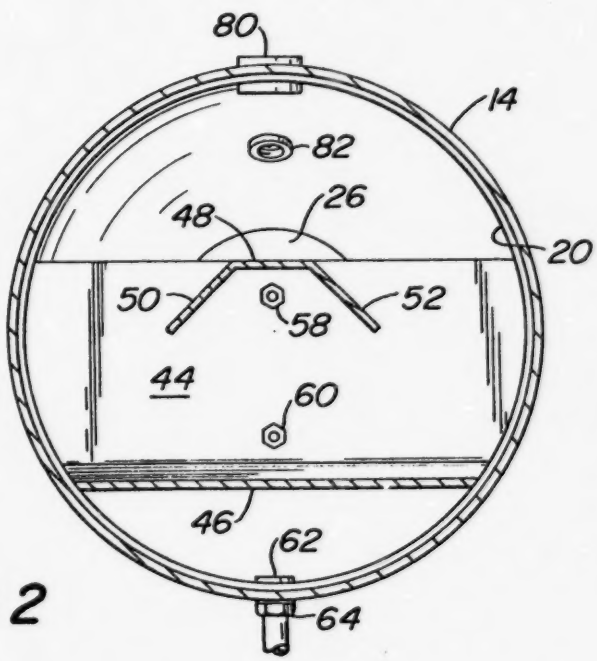
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FIG. 2

FIG. 1.

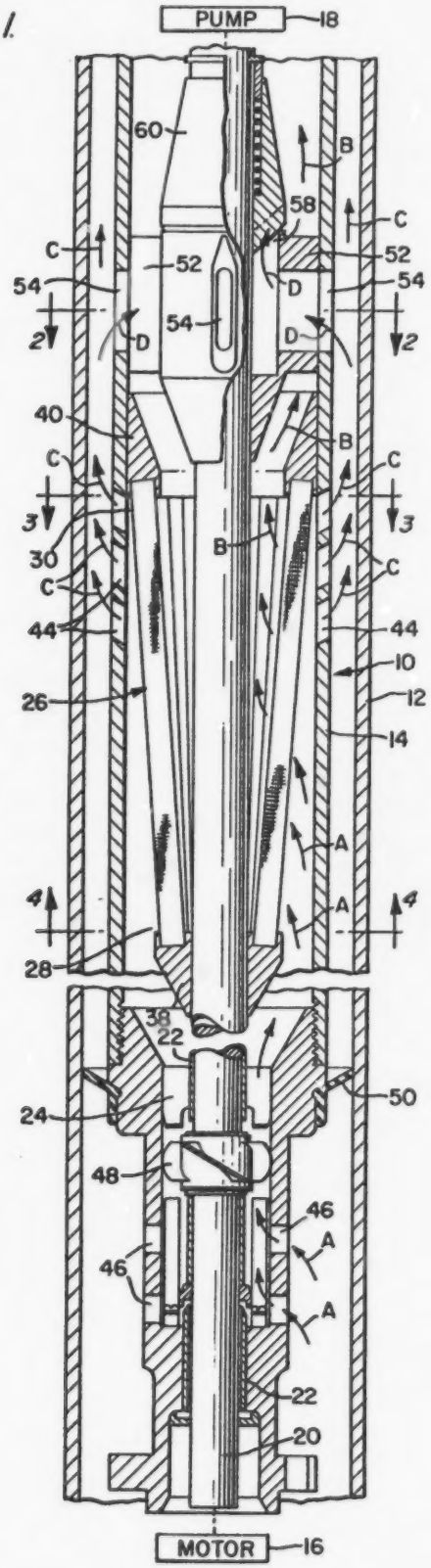


FIG. 2

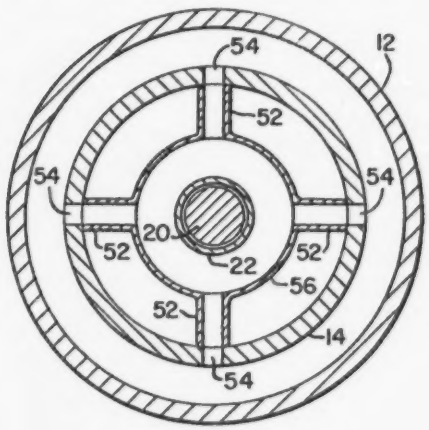


FIG. 3.

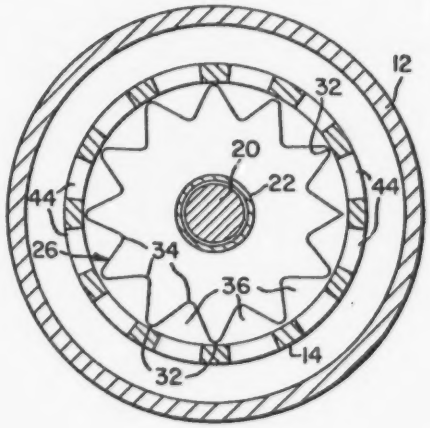
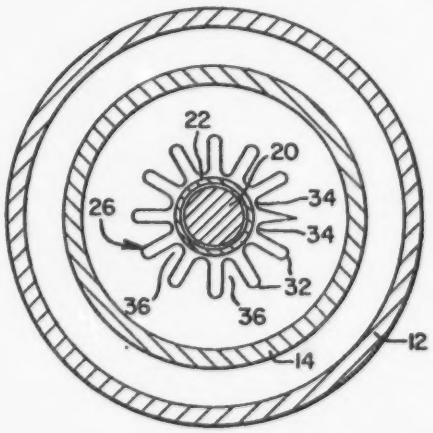


FIG. 4.



LU6611

United States Patent [19]

Coggins

[11] **3,960,525**

[45] **June 1, 1976**

[54] **OIL-GAS SEPARATOR HAVING DEFOAMING STRUCTURE**

[75] Inventor: **Robert W. Coggins**, Tulsa, Okla.

[73] Assignee: **Combustion Engineering, Inc.**, Windsor, Conn.

[22] Filed: **May 9, 1975**

[21] Appl. No.: **575,914**

[52] **U.S. Cl.** **55/178**; 55/87; 55/320; 55/327; 55/512

[51] **Int. Cl.²** **B01D 19/02**

[58] **Field of Search** 55/169, 87, 159, 171–178, 55/320, 327, 418, 512

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Primary Examiner—Bernard Nozick
Attorney, Agent, or Firm—Arthur L. Wade

[57] **ABSTRACT**

A separator vessel shell is connected to receive a mixture of fluids produced from an oil well. An inlet structure is mounted within the shell and positioned to receive the flow stream of fluid mixture. The inlet structure includes a matrix of units, each of which provide a large surface area over which the fluid mixture passes in flowing through the matrix. The forces generated on the fluid mixture convert the energy in the flowing mixture and prevent the energy from shearing vapor bubbles in the mixture and forming additional foam.

2 Claims, 3 Drawing Figures

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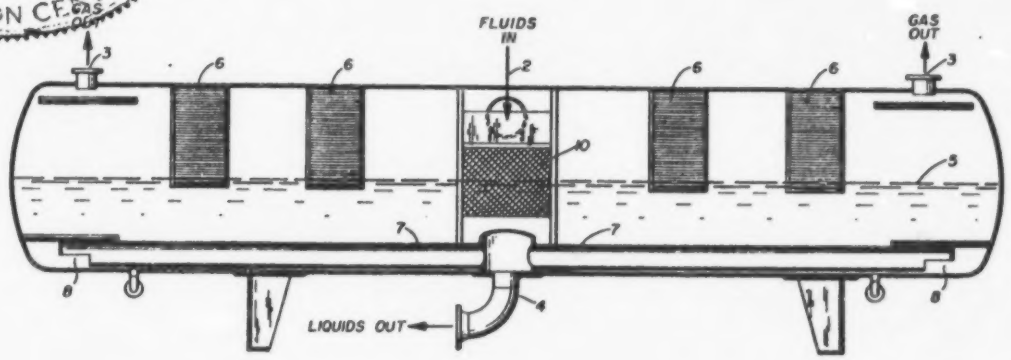


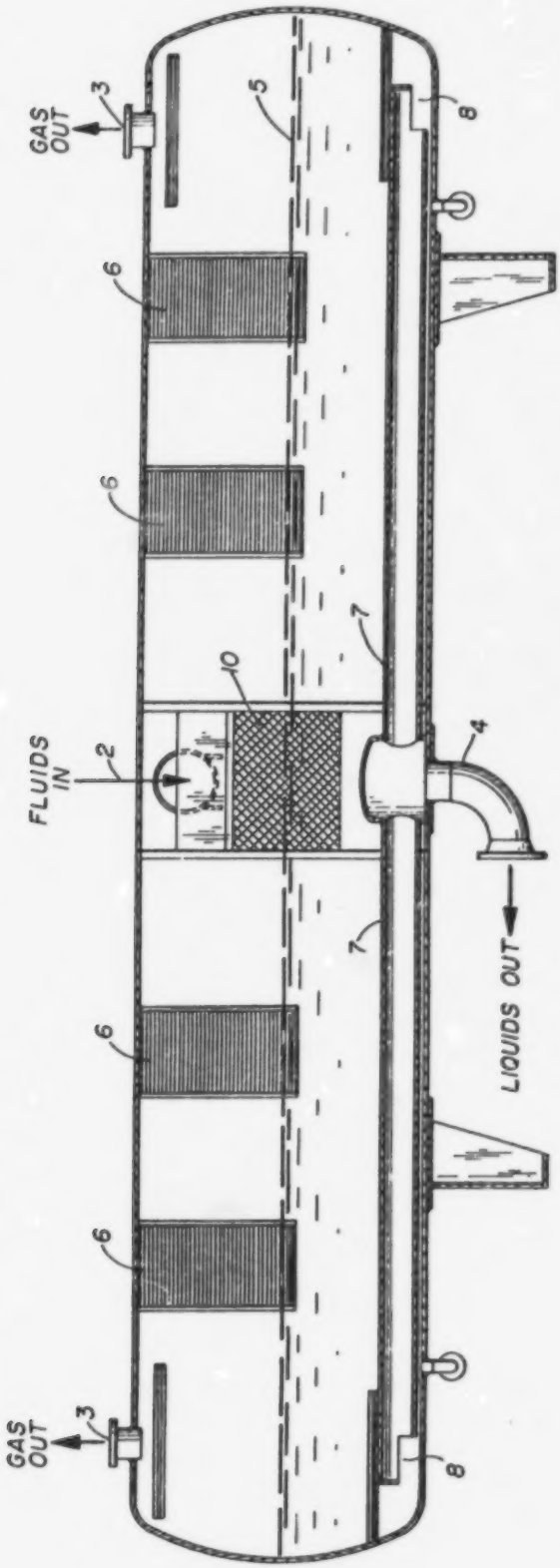


Fig. 1.

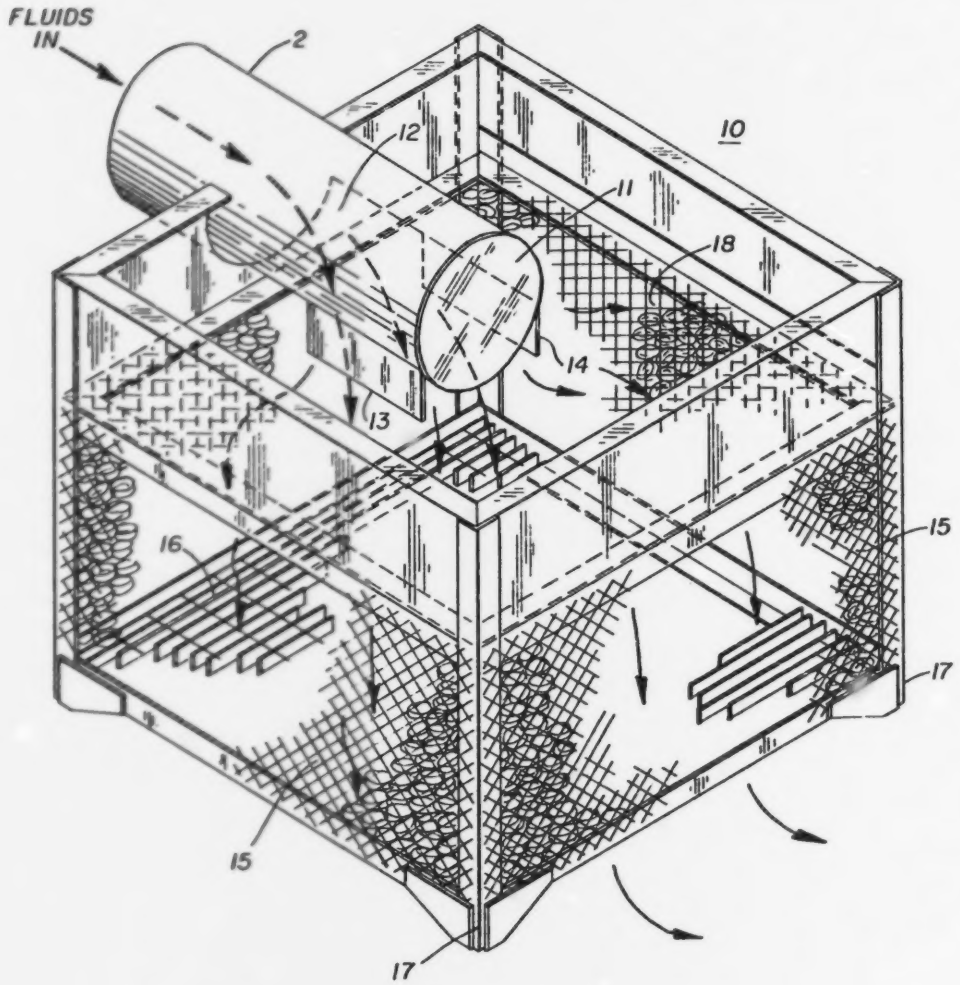


Fig. 2.

Fig. 3.

OIL-GAS SEPARATOR HAVING DEFOAMING STRUCTURE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to structures at the inlet of fluid the which absorb energy from the stream of fluids and give the first direction of the flow streams into paths for separation of the fluids from each other. More particularly, the present invention relates to inlet structure which provides a large, complex surface over which liquids containing a large amount of gas will flow without the generation of a large amount of foam with the gas and liquid.

2. Description of the Prior Art

If a separator vessel receives a fluid mixture with a high ratio of gas to liquid, the gas may form a foam with the liquid which will readily carry over to the gas outlet of the vessel. There are many factors which set the quantity and quality of the foam. But, in the final analysis, if the foam is formed, and is carried to the gas outlet, the discharge of the liquid of the foam is termed "failure" of the separator at a predetermined quantity of the liquid.

Foam in Middle East production was discussed to a great extent in the January 1964 article in the IP Review by J. D. Lowd of National Tank Company from his extensive experience with production problems in the Middle East. The sole concession to foam prevention was reference to minimizing turbulence and elimination of re-entrainment of separated phases into each other. The extension of this concept was recognition that as the fluids left the flow line and entered the vessel for separation the "inertia effects" must be quickly and effectively overcome. A carefully designed and compact device was desired to give controlled directional deceleration of the incoming fluids. Evidently, reduction of turbulence would be desired at this point.

All the problems of created foam were touched upon in the Lowd analysis. However, most of the article stepped around the foam reduction problem to study hydraulic radius control for liquid droplet removal from the otherwise separated gas stream. There remains to this day, 12 years later, the problem of effective foam prevention at the inlet separator by mechanical structure.

The oil well fluids arrive at the separator vessel as a mixture. The fluid mixture has a large store of flowing energy. The pressure upon the fluids is being reduced. The flowing energy must be absorbed to large extent. What gas is to be released from the liquids is to be released so that relatively small amounts of foam are formed. Relatively little turbulence must be introduced into the flowing stream. To carry out these functions at the inlet to the separator, a mechanical structure, or unit, must be provided.

SUMMARY OF THE INVENTION

A principle object of the invention is absorb the flowing energy of a stream of mixed fluid as the stream is received in a vessel for separation.

Another object is to flow the mixed fluid stream over a large surface so as to impart only a small degree of turbulence, the liquid component of the mixture gravitating to a low level and any gas released ascending to a higher level, the amount of foam generated being kept to a minimum.

The invention is embodied in a system for receiving a fluid stream of a mixture of fluids, the system including a vessel connected to a source of the fluid mixture, an inlet structure mounted within the vessel and comprising a number of multi-surfaced units held in a body so the fluid mixture will be discharged through the matrix of multi-surfaced units. The units are held in a body so as to provide a total surface area over which the fluid mixture will flow and contain the bubbles in the mixture to convert the flowing energy into heat and prevent shearing the bubbles to form additional foam.

Other objects, advantages and features of this invention will become apparent to one skilled in the art upon consideration of the written specification, appended claims, and attached drawings, wherein;

FIG. 1 is the sectioned elevation of the horizontal shell of an oil and gas separator with an inlet structure in which the present invention is embodied;

FIG. 2 is a perspective of a framework mounted within the shell of a separator vessel and below the inlet conduit to hold a number of Pall Rings where the incoming fluids will flow down over the Pall Rings in an embodiment of the present invention; and

FIG. 3 is a perspective of a single Pall Ring showing the details of its construction.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Long after the oil crisis, when the supply of oil imported to the United States from the Middle East was stopped, dependence of the U.S. on this oil continues. While vulnerable to future import hold-up, the U.S. equipment manufacturer supplies, and works with, the Middle East oil producer.

Diplomatic relations do not exist between Iraq and the U.S. As a matter of fact, the Soviet Union is supplying arms and military assistance to Iraq. Nevertheless, Combustion Engineering, Inc., through its division, National Tank Company (C-E Natco) sold four oil and gas separator installations to Basrah Petroleum in 1973 for its Rumaila Field in Southern Iraq. The four stations in this field are:

Qurainat	160,000 bbl/day
Shamiyah	225,000 bbl/day
Janubia	260,000 bbl/day
Rumaila	two trains of 175,000 bbl/day each

At the total of 995,000 bbl/day, at the present market price about $10/barrel, the $9.95 million/day or $3.63 billion/year brings potential financial ramifications of any improper operation in this field into sharp focus. Undoubtedly other phases of the operation of this field have faltered, but C-E Natco was suddenly faced with a specific problem which generated the present invention.

To become more specific about the problem which surfaced, the C-E Natco separators which went into operation late in 1973 were found to be capable of passing only 60% of their rated capacity. Above that limit, liquid carried over to the gas flares and generated an umbrella of black smoke the size of which could only be guessed. Apparently the particular oil at these four stations was foaming badly in the separator vessels. This foam was readily swept to the gas outlets of the vessels and swept along with the gas in liquid form.

Historically, there are prior trains of National Tank Company separators in he Rumaila Field. These separators have been operating at above their capacity ratings for several years. Chemicals have been injected into the produced fluids upstream of the separators to control the surface tension of the liquids. Foam has been avoided in the separators as their capacity ratings have been exceeded. However, the Iraq purchasing authority for the present separators insists they meet their capacity ratings without the use of chemical. Some new form of inlet had to be developed for the present separators, which inlet will dramatically prevent foam generation.

The potential of chemical anti-foam treatment was fully explored. The effectiveness of compounds used in the past was confirmed and other compounds calibrated. But the immediate inlet configuration and mechanical defoaming development received most of the attention. The result was the present invention.

The present invention is disclosed as embodied in inlet structure mounted within a horizontally extended separator shell. Also, the present invention could be said to be disclosed as embodied in a separator in which inlet structure is mounted. In either event, the essential structure embodying the invention is mounted in the separator shell to form a path, or conduit, for the liquids flowing into the shell and down to combine, or join, the collection of liquids in the bottom of the shell.

In FIG. 1, a separator shell 1 is disclosed. The specific form selected for the disclosure is that built for Basra. As in Basra, the shell 1 has its inlet 2 for the fluid mixture connected to the center of the horizontal shell. The fluids flow to each end of shell 1, hopefully after even division at the inlet. Two outlets 3 are provided for gas. A single, central outlet 4 is provided for liquids, separated from the gas.

The liquids which separate and collect in the lower portion of shell 1 form a level at 5. Normally a simple detecting device, such as a float, can sense the level 5 and put out a control signal for a valve which will control the level. In the present system, a valve is not shown but is assumed to be in outlet 4 and the level signal connected to the valve to keep the level 5 within a desired range.

It is of no particular significance to disclosure of the invention that the inlet 2 is connected to the shell 1 at its midpoint. This happened to be the design of the separators at Basra. The inlet structure receiving the incoming fluids was a centrifugal device which spun the fluids. The opinion of many engineers observing the unit in operation was that the centrifugal inlet device generated the foam which caused the carryover problem now solved by the present invention. In all events, this form of separator is used in this disclosure to embody the invention which solved the foam problem. The fluids enter the separator centrally and divide to flow toward the outlets at each end of the shell 1. The liquids are expected to sink to the lower portion of the shell 1 to form level 5. The gas is expected to disengage from the liquids and flow along the upper portion of the shell 1.

Units 6 represent any of a number of baffle structures which scrub liquids which continue to be entrained in the gas. There is no connection with the invention, but it is expected that some form of baffle structure will be made available in the upper, gas section of the shell 1 to collect liquids carried along with the gas as it flows from the inlet 2. Of course, at Basra, this neat plan was upset by the tendency of the produced oil to foam, and foam badly. These units 6 did nothing to reduce this foam and it reached gas outlets 3 well below the expected capacity of fluid throughput.

To complete the arrangement of the FIG. 1 separator, note that the liquids are removed through a single manifold pipe 7 from openings 8 at each end of pipe 7, beneath gas outlets 3. Outlet 4 is connected to the middle of this pipe 7 to remove all the liquids separated from the gas. Unnumbered plates, horizontally extended, are placed over the outlets to prevent the formation of any vortex which would apply force in the direction to draw liquids out of the gas outlets.

This setting for the invention is elementary. Separators, be they horizontal, vertical or spherical, can be first described as large volumes in a flow line for mixtures, in which residence time is provided for separation of at least the gaseous phase from the liquid phase. It could be said that the present problem surfaced when this more or less conventional separator received a mixture of gas and oil which had what can only be termed "foaming" characteristics.

It was the production into stations Q, S, J and R of the Rumaila Field that gave the unpleasant surprise of excessive foam. The centrifugal inlet design of these separators evidently stimulated more foam. Perhaps this centrifugal form of turbulence enforced the inherent tendency of the production to foam.

Specifically, the Basra crude is a 34.1° API gravity with viscosities of 55 SSU at 68°F. and 46 SSU at 100°F. with a high gas-oil ratio. Production temperature is 160°F. with a pressure of 600 pounds. Mechanical agitation, pressure drop, etc. evidently aggravates the problem — causes more foam to develop. The addition of an antifoam agent to the oil was thoroughly investigated with good progress. However, the problem remained of how to reduce the problem mechanically. This problem the present invention solved.

The mechanical solution of the foaming problem lies in the generation of a force to oppose that of the flowing energy of the fluids into the separator through their inlet. This energy of the flowing fluids can be said to be absorbed, or converted into heat. In any event, it is prevented from shearing the gaseous bubbles of the mixture and thereby generating additional foam. The required force is brought into play by a porous body formed of small multi-surfaced units through which the incoming fluids are directed and over whose total surface the fluids flow.

In FIG. 1, the surface structure which produces the desired result is indicated at 10. This unit is mounted below the inlet so it will receive the mixture of fluids as soon as it enters the separator shell. As the fluids flow over the surfaces provided by the structure 10 their flowing energy is absorbed, or converted, the gas starts its separation and the liquids are conducted into a body in the lower part of the shell without the high degree of foaming which caused the Basra separators to fail below their capacity ratings.

In FIG. 2, unit 10 is shown in good detail, mounted on the inlet 2 so as to receive the fluid mixture. "Receive" is certainly a broad description of function and more detail is required. First, note the unit 10 is mounted below the inlet 2. It is at, or close to, the bottom of the separator shell 1. Therefore, the liquids of the fluid mixture are diverted down into unit 10.

The end of inlet 2 is closed. Plate 11 is welded over the end conduit. Opening 12 is formed in the underside

of the conduit end. Further, lips 13, 14 are mounted at the sides of opening 12 to depend down and form a sort of nozzle structure to direct the fluids downward. Many specific shapes can be given this diverting, directing, nozzle structure. Whatever, the specific structure, it should function to divert the flow of fluids toward the unit 10, let the free gas which will readily disengage from the liquid flow up and away from the unit 10 and guide the liquids into immediate engagement with the surfaces provided by unit 10.

The surfaces are provided by a matrix of small bodies shaped to form a pile with each other so there is a high degree of porosity throughout the matrix with small, intricate, complex passages and an extensive total surface area. It should become evident that the matrix definition applies to the structure commonly used in towers to film liquid brought into contact with gas so there will be a thorough mixing of the two to carry out some process objective. The colloquial term is "packing." Packing, then, is the structural feature of unit 10. Many forms and materials for this packing were tested. The structure disclosed here appears, in the laboratory, to hold great promise in controlling the foaming tendencies of Basra production. In the field installation in Iraq the laboratory results were confirmed. The complete control, without chemical, is difficult to obtain mechanically. However, this disclosure was a great leap forward in preventing foam from actually being developed from oil production which has a great tendency to foam.

Unit 10 is, first of all, a framework to hold the packing bodies. It is sometimes referred to as a basket. It is disclosed here as formed of square, rigid angle members welded together to form the basket walls. Screening 15 is attached to the sides of the framework, meshed small enough to retain the packing in place. A suitable support grating 16 is formed as a bottom to the basket. The framework has legs 17 which space the support grating 16 from the bottom of the separator vessel. The result is a foraminous container, or retainer, for matrix body 18 which is mounted to hold the body 18 below the inlet 2 so the liquids will be distributed over the large, intricate surface of the packing.

FIG. 3 is the presently preferred form for the packing bodies of the matrix 18. This is a well-known form generally referred to in the trade as a Pall Ring. The exact origin of this term is obscure, but it is probably related to the name of a packing research engineer who conceived of the form as disclosed in FIG. 3. The Pall Ring is not the only form of packing body which will function under the invention. However, this form does function well and is preferred at this stage of the foam problem solving.

CONCLUSION

The invention obviously centers about the structural embodiment, matrix body 18. Those skilled in the art will readily detect I am having a problem in defining how my invention works in a way satisfactory to me. That the invention does work is undeniable. A dramatic reduction in foaming did take place in Basra when the described embodiment of my invention was substituted for the original centrifugal inlets. But just what forces did I bring into play? That is a question for which I have been seeking an answer in the laboratory. I believe my answer is now satisfactory.

I have considered deflective currents in the interstices provided by the matrix of Pall Rings. Certainly there is a large viscous drag force generated by these fluid currents. This force will absorb the flowing energy of fluids passed through the body. Perhaps it would be better if I described what takes place as a conversion of the flowing energy of the fluids into heat. In any event, the flowing energy is reduced. Less of the energy will be available to shear the gaseous bubbles to produce additional foam.

My laboratory results are a base for an additional explanation. The gaseous bubble which exists in the fluid mixture directed into the separator can be sheared, or divided, by impact upon a surface. I have found one way to avoid this shearing is to contain the bubble as it contacts an impact surface. Perhaps this is a crude statement, but my invention provides a fluid cushion about the bubble as it impacts upon a Pall Ring surface. The interstices of the matrix of Pall Rings, when filled with fluid function as this cushion.

If the size of the Pall Rings and the flow rate of the mixture into their matrix gives an effective, fluid packed, porous body, the bubbles of the mixture will not be significantly sheared. At least my laboratory results lead me to this conclusion. The incoming mixture flows into the matrix of Pall Rings. The flowing energy does not crush, or fragment, the bubbles of the mixture. The fluids in the matrix support the bubble laterally as it makes surface contact. Of course the mixture then passes through the interstices of the Pall Rings and viscous drag absorbs more energy. Overall turbulence of the fluids passed through the matrix is reduced. Shearing of the bubbles of vapor is prevented.

The deenergized liquids can then be described as easing into the body of liquids already in lower portion of the separator. A minimum of foam is additionally formed.

I have also considered the mixture of fluids as they are spread in a relatively thin layer over the surfaces of the Pall Rings. I have contemplated whether the filming of the fluids by this packing provides the short distance of travel needed for disengagement of the gas of the mixture from the liquids. Perhaps this is a result which releases gas without creating additional foam. Viscous drag, lateral fluid support and filming may all play varying parts in avoiding foam formation. It is a difficult answer to lift out of theory. At the moment I have concluded that Pall Rings, in a matrix body, sized to be liquid packed with the fluid mixture flowed into, and through, the body, give the desired result. This answer I have developed is presently satisfactory to me. I believe it to be an adequate guide for reducing the invention to practice.

From the foregoing, it will be seen that this invention is one well adapted to attain all of the ends and objects hereinabove set forth, together with other advantages which are obvious and inherent to the apparatus.

It will be understood that certain features and subcombinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of the invention.

As many possible embodiments may be made of the invention without departing from the scope thereof, it is to be understood that all matter herein set forth or shown in the accompanying drawings is to be interpreted in an illustrative and not in a limiting sense.

The invention, having been described, what is claimed is:

1. An oil and gas separator, including,

a shell into which the fluids of an oil well are conducted for separation,

an inlet connected through the wall of the shell and sized to conduct the mixture of fluids into the shell,

an outlet connected through the upper wall of the shell and remotely spaced from the inlet to conduct separated gas from the shell,

an outlet connected through the lower wall of the shell and remotely spaced from the inlet to conduct separated liquids from the shell,

a plurality of multi-surfaced packing structures held in a body with a foraminous structure mounted at a fixed location within the shell and below the inlet so as to receive the fluid mixture to liquid pack the

interstices of the body, whereby the gaseous bubbles will not be fragmented and additional foam developed as the liquids are deenergized and flow to the lower portion of the shell while the gas separates from the mixture and flows to the upper portion of the shell, and a diverting structure mounted at the inlet formed and arranged to direct the liquid downward over the packing body.

2. The separator of claim 1 in which,

the multi-surfaced structures held in a body are in the form of Pall Rings which in the body matrix provide high porosity for the body.

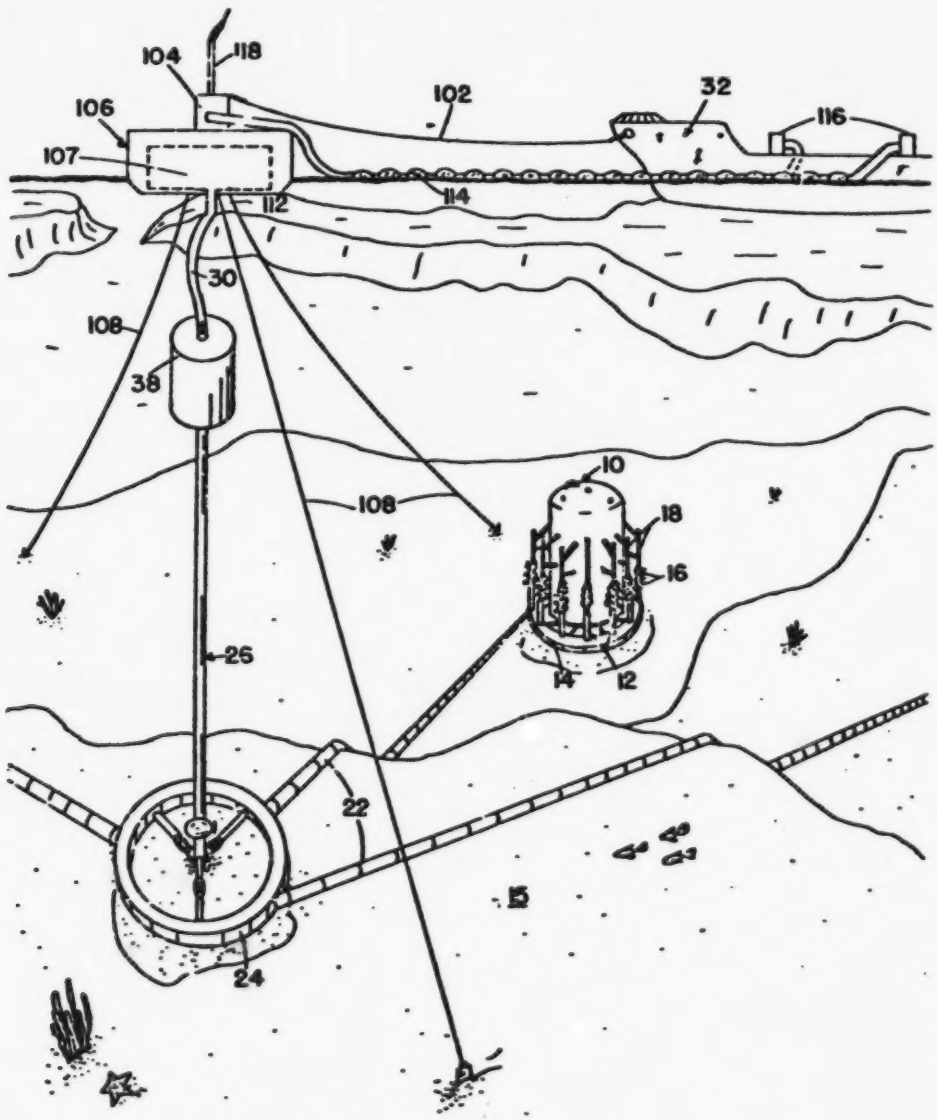
* * * * *

March 10, 1970 W. A. TALLEY, JR 3,499,266

MARINE OIL-GAS SEPARATOR

Filed Nov. 13, 1968 2 Sheets-Sheet 1

Fig. 1



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MARINE OIL-GAS SEPARATOR

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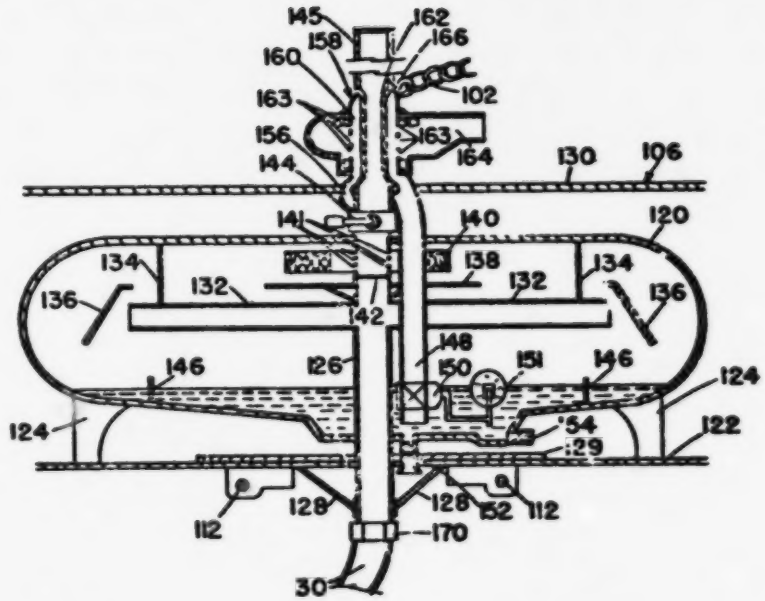
Fig. 2



United States Patent Office

3,499,266

Patented Mar. 10, 1970

3,499,266

MARINE OIL-GAS SEPARATOR

William A. Talley, Jr., Dallas, Tex., assignor to Mobil Oil Corporation, a corporation of New York

Filed Nov. 13, 1968, Ser. No. 775,235

Int. Cl. B01d 19/00

U.S. Cl. 55—169

7 Claims

ABSTRACT OF THE DISCLOSURE

The specification discloses a system for producing, separating, and storing submarine oil and gas. The system includes a floating storage vessel having a ship-shaped hull which is moored to a buoy so that it is free to pivot through 360° in response to the combined forces of wind and water. Produced fluids are directed from an underwater location through a swivel joint on the buoy and a floating hose to the storage tanks of the floating vessel. Mounted in the buoy is a unique oil-gas separator which comprises a rigid standpipe surrounded by a main pressure vessel. An inlet conduit intersects the rigid standpipe in the main pressure vessel at right angles, thus providing a pair of fluid inlets, one of which is always above the sump fluid. Separated oil is directed through a swivel joint concentric with the top of the standpipe, while separated gas is flared through an upward extension of the standpipe.

BACKGROUND OF THE INVENTION

The invention described herein relates generally to the production and storage of fluid minerals, such as oil and gas, underlying a body of water; and, more specifically, to novel separation equipment for dividing a fluid into its oil and gas components.

While it has other applications, the present invention is particularly suited for use in conjunction with the system disclosed in the copending application of Lewis A. Rupp, Ser. No. 770,350, filed Nov. 13, 1968, and entitled Floating Storage System With Buoy-Mounted Separator. The described system is an improved floating storage system which includes a storage vessel moored to a buoy. The buoy includes an oil-gas separator unit and an oil swivel joint. A floating hose extends from the oil swivel joint on the buoy to the storage tanks of the floating tanker. In response to wind and water forces, the storage vessel is free to pivot about the buoy. The separation and reduction of the produced fluid to atmospheric pressure is accomplished in the buoy, prior to being directed through the swivel joint, whereby mechanical seal pressures and other problems are obviated.

Rigid requirements are placed on oil-gas separators to be used in marine environments, particularly where there is a lot of pitch and roll caused by wave action. Such separators must be structurally strong and adaptable to unstable mounting. When ordinary oil-gas separators are used in marine operations, such as above described, a great deal of roll and pitch will cause the inlet conduit of the separator to become submerged in oil so that oil will blow through the flare stack with separated gas.

SUMMARY OF THE INVENTION

The present invention provides a novel liquid-gas separator unit to be used in marine environments. The separator unit includes a rigid standpipe around which the other separator equipment is clustered. Mounted centrally about the rigid standpipe is a main pressure vessel. An inlet conduit within the main pressure vessel intersects the rigid standpipe at a perpendicular angle, thus providing a pair of fluid inlets. The rigid standpipe extends above the main pressure vessel, the upper portion above the inlet conduit being used to draw off the separated-out gas. Gas may be flared at the upper end of the rigid standpipe through a flare stack. The upper end of the standpipe is enclosed with an outer concentric pipe through which liquids are drawn off. Surrounding the outer pipe is a rotatable yoke forming a swivel joint.

As a unique feature of the present invention, the pair of inlets provided by the inlet conduit always remains above the surface of the sump fluid. By having two fluid inlets, the liquid-gas mixture is broken up and surge shocks are lessened, thereby obviating the need for auxiliary surge vessels. The rigid standpipe is the key to the provision of an integral and strong separator structure. The unique continuous design of the rigid standpipe extending from under the separator to the flare mist provides enough rigidity for the flare stack to eliminate the need for the usual supporting tower. Another unique feature is that the liquid-gas mixture is divided toward both ends of the separator by the inlet conduit, giving increased separator capacity for unit size, lower surge problems, and less problems with unbalanced fluid levels due to wave action on the separator.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIGURE 1 is a schematic illustration of a floating storage system moored to a buoy to which this invention is particularly applicable; and

FIGURE 2 is a side elevation partially in cross section of an example separator according to the present invention.

DETAILED DESCRIPTION OF FIGURE 1

Referring to FIGURE 1, a surface storage system is illustrated utilizing a number of underwater satellite gathering stations, each having a series of wells drilled through standing conductor pipes 12 of a template ring 14 resting on the marine bottom 15. The wells are completed with underwater wellheads 16 mounted atop the conductor pipes 12 and in turn capped with connector units 18 for directing the produced fluid from the wellheads into the interior of satellite stations 10. The apparatus and method of installation of such an underwater satellite station are described in the copending application of William A. Talley, Jr., Ser. No. 740,520, filed June 27, 1968, and entitled Subsea Production Station.

The produced outputs of all of the satellite gathering stations are connected through shipping lines 22 to a circular manifold 24 located on the marine bottom 15 concentric with a tether pipe 26. Produced fluids are transported through tether pipe 26 from the marine bottom to an intermediate point several hundred feet below the water surface, where the tether pipe terminates in a buoyant chamber 38. A flexible connection 30 extends from the upper end of tether pipe 26 to a mooring buoy 106. Mooring lines 108 extend between anchor points 110 on the marine bottom to the mooring buoy 106. A separator unit 107 is shown schematically as being mounted in the hollow interior of buoy 106. Separator unit 107 is designed to separate the production flow into its liquid and gaseous components, usually into its oil and gas components. A swivel 104 is mounted atop buoy 106. A floating storage structure 32, having a ship-shaped hull, is moored by means of mooring lines 102 to the swivel 104. The floating storage structure 32 is free to pivot about the buoy 106 on its mooring line 102 in response to combined wind and water forces.

A floating hose 114 extends from an oil outlet port of swivel 104 to the storage manifolds 116 on the floating storage structure 32. A central gas flare stack 118 extends upward concentrically through the swivel 104 for burning off the separated-out gas.

By mounting separator 107 in the buoy 106, a low pressure oil is delivered to the storage facility on the

structure 32 and high pressure seals are obviated in the swivel 104.

DETAILED DESCRIPTION OF FIGURE 2

Referring to FIGURE 2, there will now be described an example of the separator unit according to the present invention which can be used in the mooring buoy 106 of FIGURE 1.

As illustrated in FIGURE 2, the separator unit includes a main pressure vessel 120 which is elongated or cigar shaped with its longest dimension extending horizontally. The main pressure vessel 120 rests on a lower bulkhead or deck 122 of the buoy 106 on integral legs 124. A rigid standpipe 126 extends fully through the pressure vessel 120, depending through the lower deck 122 from which it obtains its primary support. Standpipe 126 is rigidly connected to the lower deck 122 by means of angularly spaced diagonal struts 128. The lower end of standpipe 126 is welded directly to the lower face of deck 122 and to the upper face of a supporting plate 129, which rests on the deck 122. The standpipe 126 extends through the main pressure vessel 120 and the upper deck 130 of the buoy.

An inlet conduit 132 within the main pressure vessel 120 intersects the standpipe 126 at a perpendicular angle thus providing a pair of fluid inlets. Conduit 132 is supported by straps 134 extending downward from the upper interior wall of the pressure vessel 120. Inlet deflectors 136 are mounted in the interior of pressure vessel 120 radially downward of each end of conduit 132. A circular secondary deflector 138 is mounted concentrically on the standpipe 126 between the conduit 132 and a mist extractor 140.

Radial ports 141 are formed through the standpipe 126 within mist extractor 140. A plate 142 closes off the standpipe 126 just below the mist extractor 140.

A gas pressure valve and float assembly 144 is mounted within the standpipe 126 above pressure vessel 120 but beneath the upper deck 130 of buoy 106. Stilling baffles 146 are mounted in the sump of pressure vessel 120 as is the inlet of a discharge line 148. The entrance of liquid into the discharge line 148 is regulated by a float-controlled valve arrangement 150 including a float 151 mounted in the lower end of discharge line 148. A valved drain 152 is connected to a depressed central portion of pressure vessel 120 to direct water and other impurities from the lower end of pressure vessel 120 directly into the water beneath buoy 106. A second valved drain 154 is provided for draining the fluid from the sump of pressure vessel 120 into the hollow interior of buoy 106.

The liquid discharge line 148 is connected at its upper end to a circular manifold 156 which is mounted concentrically around the gas flare stack 145. An oil swivel 158 is located concentrically about flare stack 145 just above manifold 156 with which the oil swivel is in fluid communication. Oil swivel 158 comprises an outer stationary pipe element 160 which nests concentrically in a necked down portion 162 of pipe element 126. The pipe element 160 has radial ports 163 providing fluid communication between the interior of pipe element 160 and the interior of an outer rotatable yoke portion 164 of the swivel 158. The outer end of the yoke portion 164 is coupled to the end of the floating hose 114 shown in FIGURE 1.

At least one padeye 166 is mounted on the upper end of rotatable yoke portion 164 of the oil swivel 158 for connecting one end of the mooring line 102 which is used for mooring the floating storage structure 32 shown in FIGURE 1 to buoy 106.

In use the separator unit of FIGURE 2 is connected to a source of produced fluid such as through flexible connection 30 extending from the upper end of tether pipe 26 as described with respect to FIGURE 1. The upper end of flexible hose 30 is connected to the lower end of the rigid standpipe 126 by means of a fluidtight connector 170.

The unique continuous design of standpipe 126 from under the buoy 106 to the flare stack 145 above buoy 106 provides for rigidity and eliminates the need for a supporting tower.

By means of the inlet conduit 132 the incoming oil-gas mixture is directed in two streams toward each end of the main pressure vessel 120, thus providing increased separation capacity per unit volume of the main pressure vessel 120, lower surge problems, and less problems with the unbalanced fluid levels due to wave action on the buoy. This permits the separator to function properly even when the buoy 106 is at a considerable angle to the horizontal. With a conventional oil and gas separator mounted in buoy 106 when the buoy was inclined at an acute angle, oil would be forced through the mist extractor and out through the flare stack. This cannot happen with the present invention, where at least one of the conduits 132 is always above the oil level in the sump.

While the main pressure vessel 120 is described above as being cigar shaped, it can also be an oblate spheroid. In such an instance there could be more than one inlet conduit 132. In fact, there could be several conduits spaced at equal angles about the axis of standpipe 126 and preferably located in a plane.

The invention claimed is:

1. A liquid-gas separator comprising:
   (a) a rigid standpipe;
   (b) a main pressure vessel centrally surrounding said standpipe;
   (c) a conduit intersecting said standpipe within said main pressure vessel and providing a pair of fluid inlets from said standpipe into said pressure vessel;
   (d) a swivel assembly including a liquid outlet mounted concentrically about said standpipe above said pressure vessel;
   (e) a liquid discharge line extending from within the lower portion of said pressure vessel through the wall of said pressure vessel and in fluid communication with the interior of said swivel assembly; and
   (f) a float-controlled valve located in the lower end of said discharge line whereby liquid is permitted to flow through said discharge line and through the outlet of said swivel.

2. The separator defined by claim 1 further comprising:
   (a) a mist extractor concentrically surrounding said standpipe between said conduit and the upper wall of said pressure vessel; and
   (b) blocking means to block fluid in said standpipe between said mist extractor and said conduit, said standpipe having ports formed in the wall thereof within said mist extractor whereby gas effluent from said pressure vessel may flow through said mist extractor and thence through said rigid standpipe.

3. The separator defined by claim 1 wherein said swivel assembly comprises:
   (a) a pipe element mounted concentrically about a reduced diameter portion of said rigid standpipe, said concentric pipe elements having ports formed in the walls thereof; and
   (b) a yoke portion surrounding said concentric pipe element adjacent said ports and having an outlet pipe, said yoke portion being free to swivel about said concentric pipe element through 360° whereby liquid flowing through said discharge line may pass through the ports in said concentric pipe element and through the outlet pipe of said yoke portion.

4. The system defined by claim 3 further including a pair of deflectors located adjacent each end of said conduit in said pressure vessel and angularly positioned to deflect fluid downwardly into said pressure vessel.

5. The separator unit defined by claim 4 wherein said main pressure vessel is located within a hollow portion

of a buoy and said rigid standpipe is mounted vertically during normal use.

6. The separator defined by claim 5 wherein the lower end of said rigid standpipe extends through the lower wall of said buoy for connection to a liquid-gas mixture.

7. The separator defined by claim 5 further including in said main pressure vessel a valved drain extending from the lower portion of said main pressure vessel through the bottom wall of said buoy.

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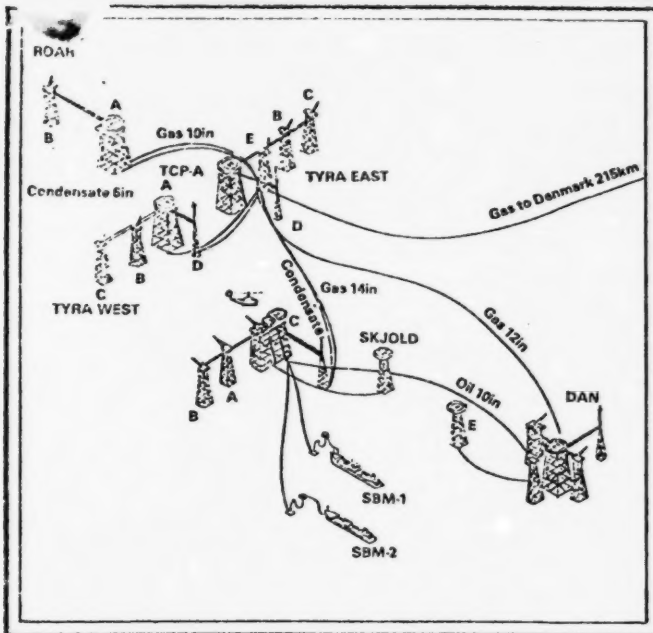
REUBEN FRIEDMAN, Primary Examiner

R. W. BURKS, Assistant Examiner



GORM RISES AS DAN DECLINES

The Gorm field offshore Denmark is due on stream this month. It is the largest development undertaken by the Dansk Undergrunds Consortium (DUC), with four platforms expected to produce 30,000-40,000b/d from total recoverable reserves estimated at 110-200 million tonnes.

There are two production platforms (A and B), built by UIE of Cherbourg in France. An accommodation platform (C) and emergency flare tower (D) were fabricated by Dutch company NAPM. The four platforms are joined by bridges and sited in around 38m water depth. The nine production wells on both A and B platforms are split into seven oil and two gas producers. All were drilled by the *Maersk Explorer* through the jackets.

Topside oil and gas facilities have been engineered by Fluor Ocean Services in London at an estimated cost of £35.75 million. Operatorship is now held by Dansk Boreselskab. It was previously in the hands of DUC partner Chevron, which has a 15% stake in DUC's south-western concession. Other partners include Shell with 40%, AP Moeller with 30%, Texaco 15%.

Last month the Danish Government ended DUC's monopoly of all exploration and development offshore Denmark. DUC now holds just the south-west operating area where present finds are located.

The consortium's first oilfield development was Dan field, which came on stream in 1972. Although production capacity is set at 30,000b/d, production is declining and last year was 7,500b/d. A further development of a £340 million gas gathering project is being planned to include both Dan and Gorm and new fields Skjold, Roar and Tyra.

Small though it is, the Gorm development has seen the first commercial application of a highly interesting new technique — the suction pile. Shell, a major partner in the field, has been developing the suction pile for some years and the two SBMs at Gorm are each being anchored by six such devices.

In this article, **Dr John Cuckson** of SBM Inc describes the Gorm application. We also report Cuckson's views on the potential in general of the suction pile.

THE SUCTION PILE FINDS ITS PLACE

The two oil loading terminals for the Danske Boreselskab (Danbor) Gorm field, offshore Denmark, will be the first to be anchored on SBM Inc suction piles. All the piles have now been installed, and one SBM. The second SBM is due to be placed in April or May this year.

Developed by Shell and licensed to SBM, the suction pile concept is an exciting innovation in offshore foundations. The concept is especially attractive for securing large structures in deep water, where the cost of scaling up existing techniques becomes prohibitive.

The principle is to force the suction pile into the seabed by creating a pressure difference across its inside and outside walls. To do this, its top is closed and the pile is first allowed to stand on the seabed under its own weight. Its sidewalls then penetrate far enough into the seabed to form a seal around the lower edge of the pile. By pumping out the water trapped inside it, plus the seepage flow, the pile can be forced completely into the seabed.

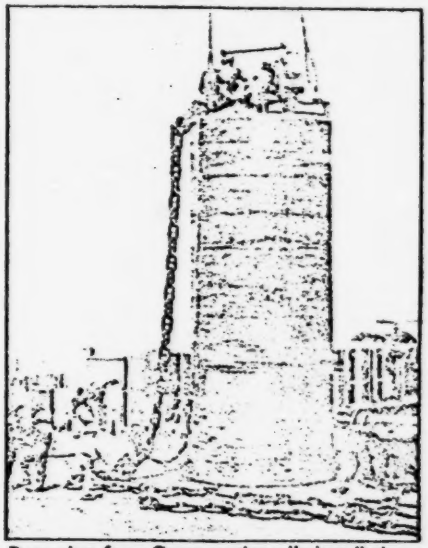
Once it has penetrated the seabed to its full design depth, the pump is stopped and the pore pressures in the soil around the pipe regain their ambient values. Consequently foundation loads are reacted by the soil in the same way as with any conventionally driven or drilled pile and no reliance whatever is placed on maintaining suction in operation. This contrasts with several other concepts where the holding capacity of the suction anchor pile relies on negative pore water pressures, or on the effects of consolidation in the surrounding soil.

The suction piles for the Gorm field were designed to resist a force of 200t applied by the terminal's most heavily loaded mooring chain. It happens that in this specific case the external force is purely horizontal, but suction piles can also resist load applied in any direction.

Because of the short delivery period, the piles for Gorm were designed to be fabricated entirely from flat plate with a flat end closure. This was also convenient from a structural view point, since the radially stiffened flat end could also act as a shear diaphragm to spread the mooring load from the 125mm thick shackle connection to the 25mm wall of the suction piles.

Generally, soil conditions at Gorm are characterised by a dense fine sand layer overlying a thin layer of soft clay which is underlain in turn by stiff clay. A striking feature of the sand is that at about 3m below seabed its relative density increases sharply, leading to cone penetration resistances far in excess of what had been encountered in previous tests (reported by Shell's Jan Hogervorst at OTC last year). Each of the 12 pile locations was evaluated separately at the design stage, but the final dimensions were standardised at 3.5m dia and either 8.5m or 9m length depending on the depth of the stiff clay. This meant the anchors had to penetrate under suction a sequence of medium to fine sands, soft clay and finally stiff clay.

Prior to installation, each pile was fitted with two removable submersible pumps, an instrument package and back-up jetting facilities. The instrument package measured pile penetration, pile inclination and



Preparing for a Gorm suction pile installation.

differential pressure, and all readings were put in a control cabin set up on the deck of the work vessel. The jetting facilities were provided in case of unforeseen difficulties, perhaps due to local soil variations, especially in the sands, which the geotechnical survey had failed to identify.

Each pile was lowered by crane over the side of the installation vessel with one end of the 95mm mooring chain shackled to the pile's mooring lug and with an umbilical for power and instrumentation. Air trapped inside the pile escaped quickly enough through the outlets of the two pumps for the pile never to be buoyant.

As the edge of the anchor touched seabed the crane tension was reduced so that the anchor penetrated under its own weight to form an initial seal. The pumps were then started and the crane tension released.

It was found that the anchor penetrated steadily even through the dense sand and that it remained within a few degrees of vertical, but in a few cases the level of soil inside the pile rose far enough to prevent full penetration.

In these cases the piles were extracted a metre or so by closing the inlets to the suction pumps and pressurising the piles using a tapping to the jet system. This tapping was then closed, the suction pumps restarted and jet circulation established from the jet pipes inside the upper part of the anchor. This flow was sufficient to carry the top of the soil plug out through the suction pumps. The jet flow was then stopped and the piles installed to their full penetration under suction.

Once this was achieved the suction pumps were stopped and recovered together with the instrumentation package, ready for re-use on the next pile to be installed.

The work vessel was then moved toward the centre of the terminal's mooring pattern in order to lay down the 300m of chain previously set out on deck. This enabled a load test to be carried out in which pile head deflections were measured. Loads of up to 230t resulted in pile head deflections of the order of 20mm. This was less than predicted, and reflects both the very high relative density of the sand and the benefits of three-dimensional effects, which are usually ignored in conventional pile design.

Each pile took between one and two hours to install, excluding rigging and barge moves. This compares very favourably with installation times of driven piles of similar capacity. In deeper water where pile follower handling takes comparatively more time and where weather downtime tends to rise, the suction pile becomes increasingly more attractive, since it avoids the mooring and handling problems which make conventional piling so expensive.

ALTERNATIVE THAT WORKS WELL IN DEEP WATERS AND POOR SOIL

Every company is stuck when it comes to installing piles without support in very deep water — it is a major problem looking for a solution according to Dr John Cuckson, manager of installation procedures for SBM Inc in Monte Carlo.

He joined the company in 1975, after soil mechanics work at Cambridge University, at a time when SBM was beginning to expand its product line into full-scale floating terminals as opposed to mooring buoys alone, and was starting to look at alternatives to pile-driving.

The ideal of a self-installing device requiring support only from small vessels, and therefore feasible in remote parts of the world, looked achievable with suction anchors and SBM began devoting energy in this direction.

Shell had already launched into serious development work on suction piles, culminating in a year-long series of full-scale anchor tests at a variety of locations using a 3.8m dia pile varying in length between 5m and 10m. In 1979, SBM tapped into this expertise through a licensing agreement with Shell.

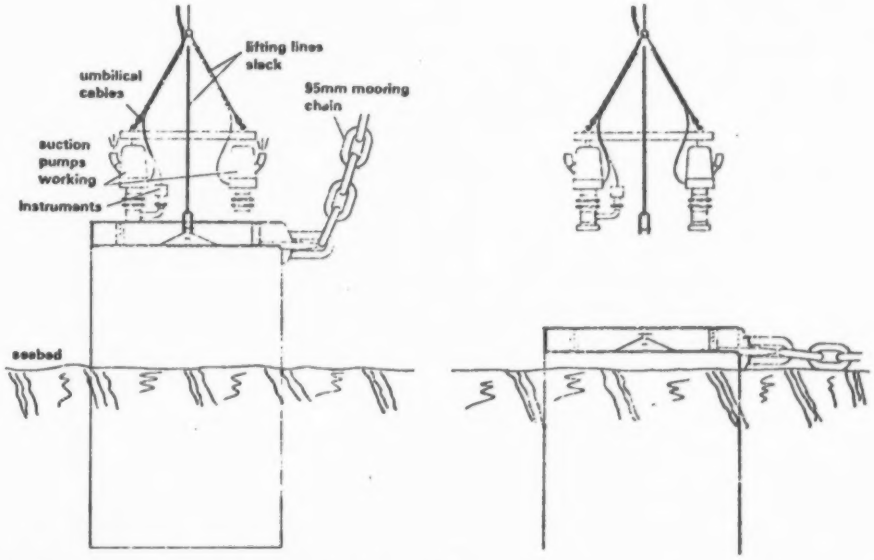
'The technique is really only an extension of gravity platform practice', says Cuckson. 'In principle it is just a matter of extending the skirts of a gravity base and using suction to get it in. The deeper you go the better, because, while driving resistance does not increase with depth, the force available for driving increases by one tonne per square metre of anchor surface for every extra metre of water depth.'

The same principle can be used to remove an anchor, simply by reversing pump flow. The application at Gorm — for SBM anchors — is typical of the early roles foreseen for suction piles. They should also find a place in poorish soils at 70-200m water depth for more substantial articulated mooring points or floating production systems, where the requirement is for an uplift resistance of perhaps 1,000t (half against static loading, and half against dynamic) and lateral resistance of 500t.

'There is really no limit to capacity', says John Cuckson, 'for example the technique could be applied for a yoke anchorage using a suction pile perhaps 20m or 30m square. Other applications could be to prestress the foundations under jack-up legs — where the spud can is just about the right size; or to replace a group of conventional piles with a single suction pile'.

'An obvious extension', he points out, 'is to replace the piles of a jacket by a number of suction anchors, most likely incorporated in a grid over the jacket base. This is feasible at a number of locations studied. End bearing resistance as well as skin friction could be mobilised by grouting inside the pile.

'On a smaller scale the same principle could be used for a subsea wellhead template, with the added advantage that the template can be levelled by control of suction'.



Left: *After touchdown of the suction pile on the seabed, emplacement begins by activating the pumps.* **Right:** *Pumps are later released and recovered, leaving the mooring chain lying horizontally on the seabed.*

NEW FLEXIBLE PIPELINE: A FUTURE ALTERNATIVE TO COFLEXIP?

The West German firm Paguag is now well on its way to producing a 'really flexible' elastomeric pipeline; a rival to the thermoplastic variety from the French company Coflexip.

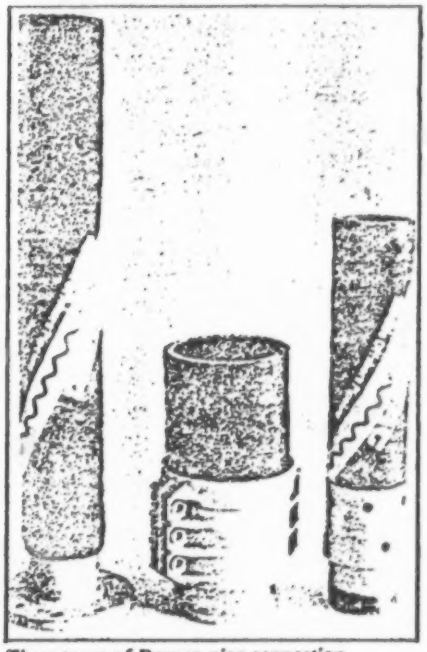
Dr Karl-Heinz Pahl is convinced that when it comes to flexibles, 'there is not just one offshore answer. . . our products are custom built.' He is the grandson of the founder of the 85-year-old company. 'We started as a hose manufacturer,' he says.

It was Dr Pahl's father who 51 years ago invented a hose manufacturing method based on a mandrel and using reinforcement in spirals, wound at a 'neutral' angle. The angle must not be so acute that the hose becomes stiff. If the angle is too wide, then the hose may shorten when it is subjected to high internal pressure.

Developed over a five-year period, and with sponsoring from the West German government, the basic Paguag offshore pipeline incorporates a number of different rubber compounds. The inner lining of the typical pipeline is based on elastomers of nitrile rubber. Chloroprene compounds form the basis of the bonding material between the reinforcing layers and the outer cover.

Brassed steelcord wire is typically used for reinforcement, though for a lightweight product, aramide filaments can be included. For high pressure applications, more steel wire is used, and variable buoyancy can be provided by the use of rubber compounds of different specific gravity.

Paguag's pipelines are claimed to provide outstanding fatigue properties. They are unusual in that the components are bonded together in a vulcanisation process which means there is no wear to cause frictional heating between the steel reinforcement wires.



Three types of Paguag pipe connection.

Project manager Dr Rainer Vettermann explains: 'Our product is homogeneous. All the reinforcing layers along the hose carry an equal tensile load.' He substantiated this with a demonstration of the results of a burst pressure test on a 4in dia hose. Three tear failures occurred simultaneously. 'This indicates the uniformity of the stress throughout the hose', says the enthusiastic Vettermann.

Special rubber compounds are not new to the company, for some 60% of its business is in specialist moulded and bonded rubber products for the car industry and for such diverse applications as roller coverings, conveyor belts and escalator handrails.

Says vice-president, Dr Miklos Dóbó, responsible for the 70-strong research team. 'We develop our own compounds and we have perhaps as many as 500 standard ones. A new material could use as many as 50 different components.' Paguag's laboratories have tested the flexible hose materials both physically and chemically.

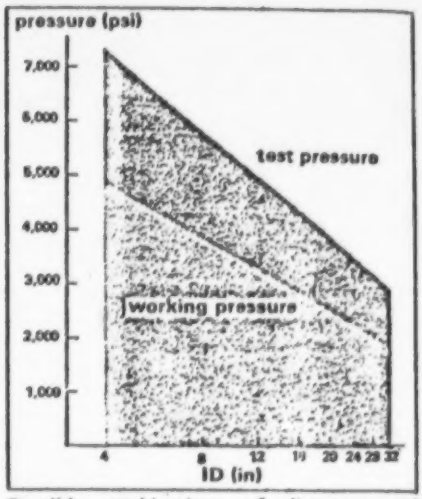
Tests include abrasion, adhesion, ageing, chemical resistance at high temperatures, tear resistance and viscosity to fatigue, wear, and burst pressure. A high pressure pipeline was found to maintain its pressure capability, even after five million cycles of bending with radii as small as 6 x id. 'We can say we have good chemical resistance for all oil applications' says Dóbó.

Paguag says that its pipelines are suitable for loading, injection, crude testing, expansion loops, riser tie-ins and repairs to steel pipes, and, with special insulation material, even for lng handling. 'Within 12 months we will be able to provide any company with flexible lng or lpg lines', the company confidently claims.

In 1978, a 1/25th scale Paguag flexible was tried for lng handling applications in the wave basin of the Hamburg Ship Research Institute, in conjunction with LGA Gastechnik. Full scale would be id 200mm and od 508mm, according to Paguag, and in this case, the inner lining was a reinforced Teflon material. Insulation was a special polyurethane foam and the outer cover was a textile reinforced rubber hose with additional windings to resist hydrostatic pressure.

First reinforced rubber hoses for offshore have already been manufactured at the company's Düsseldorf headquarters, though as yet 38m is the longest length possible.

One 30cm dia, 10m length of Paguag Offshore Flexible Pipe has been supplied to



Possible combinations of diameters and pressures.

BP Germany for a working pressure of only 230psi at an inshore terminal and while the order is acknowledged to be 'nothing outstanding' it is deemed a 'significant beginning'.

More significant perhaps was the testing of Paguag pipe during the pilot trials of Bilfinger and Berger's Conat articulated tower last year. A full 38m length of 101mm id standard design was tested as a 'loading line' for the 'tanker' in the simulated test. Stresses on the pipeline terminal couplings were monitored.

Recommended connections for the pipe says Paguag, are 'proved to be safe and reliable'. In order of increasing pressure capability, they are re-usable bolted half shells; swaged-on (can be field fitted); and vulcanised, built-in connections for heavy duty (see picture).

Now that the company is satisfied that its production method is well proven, the next stage will be to use a continuous manufacturing technique, but it says that it does not want to take this step alone. In a joint venture development, lasting between two and three years, Paguag is intending to install a pilot plant for a continuous 10in dia hose. Maximum working pressure envisaged for the range of pipes is around 5,000psi and the maximum id is 32in. Tfl applications are now being considered.

Blohm and Voss of West Germany has designed a vessel for constructing and laying 20in dia flexible pipeline in water depths down to 1,000m and, says Paguag, 'We have been asked to develop suitable 16in hoses for a brand new loading system, with a Norwegian company, for an early production system for 125m water.'

Paguag is discussing possible applications in Mexico with state-owned Pemex, in UK and offshore Brazil.

POOR

QUALITY

ORIGINAL